AD-A173 547

VOLUME 18, NO. 7
JULY 1986

THE SHOCK AND VIBRATION DIGEST

A PUBLICATION OF
THE SHOCK AND VIBRATION
INFORMATION CENTER
NAVAL RESEARCH LABORATORY
WASHINGTON, D.C.

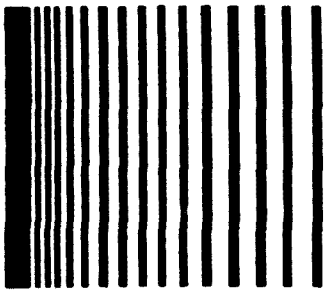
DTIC
ELECTE
OCT 23 1986
S D
E

DTIC FILE COPY

OFFICE OF
THE UNDER
SECRETARY
OF DEFENSE
FOR RESEARCH
AND
ENGINEERING

Approved for public release; distribution unlimited.

88 10 20 050



THE SHOCK AND VIBRATION DIGEST

Volume 18, No. 7
July 1986

STAFF

Shock and Vibration Information Center

EDITORIAL ADVISOR: Dr. J. Gordan Showalter

Vibration Institute

EDITOR: Judith Nagle-Eshleman
TECHNICAL EDITOR: Ronald L. Eshleman
RESEARCH EDITOR: Milda Z. Tamulionis
COPY EDITOR: Loretta G. Twohig
PRODUCTION: Barbara K. Solt
Gwen M. Wassilak

BOARD OF EDITORS

R.L. Bort
J.D.C. Crisp
D.J. Johns
B.N. Leis
K.E. McKee
C.T. Morrow
W.D. Pilkey
H.C. Pusey
E. Sevin
R.A. Skop
R.H. Volin
H.E. von Gierke

The **Shock and Vibration Digest** is a monthly publication of the Shock and Vibration Information Center. The goal of the Digest is to provide efficient transfer of sound, shock, and vibration technology among researchers and practicing engineers. Subjective and objective analyses of the literature are provided along with news and editorial material. News items and articles to be considered for publication should be submitted to:

Dr. R.L. Eshleman
Vibration Institute
Suite 206, 101 West 55th Street
Clarendon Hills, Illinois 60514
(312) 654-2254

Copies of articles abstracted are not available from the Shock and Vibration Information Center (except for those generated by SVIC). Inquiries should be directed to library resources, authors, or the original publishers.

This periodical is for sale on subscription at an annual rate of $200.00. For foreign subscribers, there is an additional 25 percent charge for overseas delivery on both regular subscriptions and back issues. Subscriptions are accepted for the calendar year, beginning with the January issue. Back issues are available -- Volumes 11 through 16 -- for $40.00. Orders may be forwarded at any time to SVIC, Code 5804, Naval Research Laboratory, Washington, D.C. 20375-5000. The Secretary of the Navy has determined that this publication is necessary in the transaction of business required by law of the Department of the Navy. Funds for printing of this publication have been approved by the Navy Publications and Printing Policy Committee.

A publication of

THE SHOCK AND VIBRATION INFORMATION CENTER

Code 5804, Naval Research Laboratory
Washington, D.C. 20375-5000
(202) 767-2220

Dr. J. Gordan Showalter
Acting Director

Rudolph H. Volin

Elizabeth A. McLaughlin

Mary K. Gobbett

SVIC NOTES

State-of-the-Art Comparisons

Round robin surveys have been carried out in the shock and vibration field, and in other technical fields, to assess the state-of-the-art of performing various tasks. Most of the surveys in the shock and vibration field were undertaken to assess the state-of-the-art of measuring the dynamic properties of structures, but papers were presented at two recent Shock and Vibration Symposia on the results of two surveys that were undertaken to assess the state-of-the-art of predicting the dynamic characteristics of structures.

Whatever their purpose, these surveys are useful in the shock and vibration field, and in many other fields, for many reasons. Their results may help identify analysis or measurement practices that produce spurious results. The results of such surveys are often a benchmark that may be used by the participants to evaluate their own capabilities. But, more important, in the shock and vibration field, the results of these surveys indicate the degree of consistency to be expected in structural dynamics measurements and analyses. They may also provide insight into the expected bounds on the measured or the predicted dynamic properties of structures that are obtained by different, experienced investigators. This is useful because most major systems are composed of subsystems that are furnished by different organizations. To ensure a system's dynamic characteristics will fall within certain limits, one must have some idea of the consistency of the measured or the predicted dynamic characteristics of its subsystems.

Round robin surveys have been undertaken to perform specific evaluations or comparisons. One survey was undertaken to evaluate the sensitivity of the changes in several types of structural signatures to changes in the structural characteristics of offshore oil drilling platforms that might indicate incipient damage. Some of the signature changes that were evaluated included the modal characteristics, the frequency response, and the random decrement. Another survey was carried out during the modal tests on the Galileo spacecraft to compare the modal properties of that spacecraft when different modal testing and analysis procedures were used.

One of the difficulties with round robin surveys, regardless of their purpose, is properly interpreting the significance of the results. Of the two types of surveys, I believe it is more difficult to properly interpret the significance of round robin surveys that are undertaken to compare or evaluate different ways of doing things. But when interpreted properly, the results of both types of round robin surveys provide useful information.

RHV

Accession For
NTIS GRA&I
DTIC TAB
Unannounced
Justification
$200.00 ANNUALLY
By NRL
Distribution/
Availability Codes
Dist | Avail and/or Special
A-1 | 21

QUALITY INSPECTED 4

DTIC ELECTE
1986

EDITORS RATTLE SPACE

SOME REFLECTIONS ON STANDARDS DEVELOPMENT

Some persons have been critical of the U.S. standards program whether it be American National Standards Institute (ANSI), industrial, or government directed. Others are not aware that such activity exists. However many people are interested in using the results of these programs. Unfortunately too little attention is paid to standards programs by too few people. In general, the result is a slow moving standards process. However, where specific industrial user and manufacturer groups are involved, standards and specifications are developed at a faster pace but are not coordinated with other groups.

The U.S has chosen a voluntary standards program. This means that technical persons who represent all aspects of industry and government are asked to contribute their time and resources. The administrative aspects of the programs are staffed by the various standards groups. For instance the Acoustical Society of America provides the administrative support for the mechanical vibration and shock activity of ANSI. I believe this type of organization is a good one -- where a good administrative staff provides the mechanism and procedures for the development of standards. This means that the technical people do not have to be involved with administration and can devote a small intense fraction of their time to the program. It provides input from highly skilled technicians who otherwise would not be interested in this type effort. The administrative staff provide direction and continuity in format and style, ensure fairness, and organize committees. The greatest problem with the voluntary program is its slow pace. This is due to the unavailability of dedicated technical volunteers which, for a number of reasons, industry does not provide.

Basically I believe the voluntary standards concept is a good one. A good product evolves from the system. Perhaps it is not all bad that it takes so long. Standards development is an intense distillation process. Procedures, criteria, and acceptable levels, developed for qualitative judgement of environmental conditions and systems, are based on available data and technology. Since standards development does involve distillation of technology to basics, it takes time and reflection to come to the right decisions. Accurately obtained field data are needed to verify charts and tables generated. It appears to me that the use of a staff liaison (STL) could increase the pace of this process. This person would function in a manner similar to trade magazine technical editors -- gathering data, ideas, and information from experts to generate current interest articles. The STL could gather information, data, and concepts to form the framework for standards. In this mode of operation, the technical experts would be engaged only in very specific contributions and comment. It could relieve them from long laborious meetings (and travel) involving format and style. Of course, the STL would have to be financially supported. Perhaps this could be effected from the increased sale of documents and contributions from industry and government agencies.

SUBSTRUCTURING AND COMPONENT MODE SYNTHESIS

R. Greif*

Abstract. This article summarizes work since 1983 on substructure analysis and component mode synthesis of vibrating systems. It is an update of an article published in January, 1983. Among the topics discussed are recent theoretical developments, error estimates due to truncation procedures, and damping synthesis. The discussion includes combined experimental/analytical modeling and applications to a variety of engineering problems.

Substructuring and synthesis techniques are used extensively for the analysis of complex structures in terms of simpler substructures and components. Efficiency is typically gained by describing the vibration characteristics of a component in terms of a truncated set of modal properties. The system model is obtained by enforcing compatibility and equilibrium along component interfaces. These concepts are included in modern texts [1-3].

Recent theoretical developments include optimum truncation level, use of admissible functions in substructures, and frequency domain methods. Work using modern interactive computer techniques to merge laboratory measurements with analytical procedures has further enhanced the utility of the substructure/synthesis method.

Two recent general papers present excellent overviews of analytical synthesis techniques [4] and modal testing techniques [5]. Craig [4] considers various types of component modes and their relationship to component testing. He briefly discusses complex modes for damped systems and also frequency domain component mode synthesis methods for damped systems. Ewins [5] examines systems that include component characteristics determined from test data, rather than from typical analytical models such as are used in the finite element method. He points out the advantages of using free structures as components in a testing situation in conjunction with stiffness and damping connecting elements. A careful discussion is given of frequency domain methods to characterize component response.

The present paper is an update of previous work [6] and concentrates on the component mode synthesis (CMS) method. In general, references of the current paper do not duplicate those of the earlier paper.

THEORETICAL DEVELOPMENTS

Theoretical work has been done to establish the proper substructure modal characteristics needed to accurately predict natural frequencies and modal characteristics of a system in a specified frequency range. Kuang and Tsuei [7] have investigated substructures based on three mode sets, inertia, and selected normal and residual modes. Various substructure approximations are based on energy considerations. For example, contributions from high-frequency kinetic energy and low-frequency potential energy (or vice versa) are neglected. An analysis of a cantilever plate system produced excellent results in a specified frequency range.

In Kubomura's approach [8], approximations are made for the generalized coordinates of the substructure modes with frequencies larger and smaller than the system frequencies of interest. Based on results for a beam system, Kubomura stated a criterion for retention of substructure modes. "A conservative criterion for the range of component modes needed is to retain all component modes whose eigenvalues are below 2.25 (1.5^2) times the highest system eigenvalues of interest and above 40% of the lowest system eigenvalues."

Curnier [9] compared substructure modes based on fixed, free, or loaded interfaces. The free and fixed interfaces are interpreted as limiting cases of the general loaded interface. A numerical study of truncation is done for a six-degree-of-freedom (DOF) two substructure model associated with a spacecraft. A 13 DOF system was also studied to assess the trends due to model truncation. The author concluded that the loaded interface model produces the most accurate results; however, implementation is complex in comparison to the fixed interface version, and this complexity remains a strong impediment to use of the loaded interface model.

* Professor and Chairman, Department of Mechanical Engineering, Tufts University, Medford, Massachusetts 02155

Sekimoto [10] considered modal synthesis for beam problems with interfaces loaded by masses containing both translational and rotational inertia. A modal truncation study was done for two beams with a common interface because the inertias are parametrically varied. A comparison of experimental and analytical results is given for a system consisting of three substructures --two box-shaped frames connected with a honeycomb panel.

Shabana and Wehage [11] investigated the dynamic analysis of systems composed of rigid and elastic bodies including the highly nonlinear effects of large angular rotations. They used finite element shape functions to describe element deformation. Modal analysis and substructuring of individual elastic elements were used to eliminate unimportant modes and produce an efficient system formulation in terms of mixed sets of modal and generalized reference coordinates. Numerical results are presented for several linkages with flexible elements.

Shabana [12] considered similar nonlinear systems but described element deformation in terms of substructure shape functions and shape vectors. The substructure characteristics can also be determined experimentally through the use of parameter identification techniques [13].

Many authors have considered the implications of using the Rayleigh-Ritz method to reduce the order of the substructure eigenvalue problem. Subspace iteration is often used. In this process improved Ritz trial vectors are generated, the eigenvalue is solved again, and the process is repeated iteratively. Compatibility is used to combine these reduced substructures into a structural system for solution of the overall eigenvalue problem. The implications of these methods have been studied [14-16]. Admissible functions (or vectors) for the substructures have been explored and the system connected together using approximate geometric compatibility via the weighted residual method. Convergence of the eigenproblem is studied by increasing the number of substructure admissible functions and the number of internal boundary weighting functions.

Improved admissible substructure functions have been found through use of the subspace iteration algorithm [17]. It was pointed out that each substructure computation can be performed independently of the other substructures; they can thus be carried out in parallel. A study of subspace iteration algorithms associated with multiple levels (in the sense of the modeling process) of substructuring has been published [18]. Software engineering concepts required for the computer implementation of these multilevel substructuring algorithms have been examined [19]. Engels [20] discussed the Hurty-Craig-Bampton CMS technique for a two-component system; solution of the resulting eigenvalue problem was obtained by subspace iteration. When the number of interface degrees of freedom is small, substantial computer cost savings can be achieved. The physical system implied in this work is related to booster and payload components for the space shuttle.

Matta [21] discussed calculation of Ritz basis vectors for static condensation and component mode synthesis techniques. A procedure for selecting the best dynamic degrees of freedom for dynamic analysis is based upon the properties of the diagonal terms in the basic mass and stiffness matrices of the structure. Wilson [22,23] used a new technique to generate a sequence of Ritz vectors to reduce the size of a system. The first Ritz vector is the displacement vector obtained from a static analysis using the spatial distribution of the dynamic load vector. Subsequent vectors are found from a recurrence relationship in which the load vector for a static solution is obtained by multiplying the mass matrix by the previously obtained Ritz vector. The vectors are mass orthogonalized at each step. These orthogonal Ritz vectors provide a mathematical basis for transformation to a smaller set of coordinates. The reduced set of coupled equations can then be solved by numerical integration techniques or by an eigenvalue modal analysis.

DAMPING AND DAMPING SYNTHESIS

The subject of damping and damping synthesis has been actively researched recently. Modern computer techniques such as interactive processing of laboratory measurements have allowed analytical and experimental methods to produce more accurate results than previously. Parameter estimation techniques can be used to accurately resolve the phases of the modes. Hale [24] extended earlier work [17] to include general nonconservative systems composed of substructures. Viscous damping and gyroscopic forces are included on the substructure level through the use of a state space formulation. Reduced order substructure models are obtained by approximating each state space vector as a linear combination of real trial vectors that are iteratively increased in accuracy.

Hale and Bergman [25] extended these ideas by using free vibration tests to obtain substructure characteristics. Measurements at discrete times

are made for fixed spatial locations. A time domain method -- the auto-regressive moving-average method -- yields a discrete time recurrence equation for measured quantities from which state equations can be obtained.

Wu and Greif [26,27] investigated damped systems by a successive transformation method based on free interface modes followed by fixed interface modes. This technique uses state space form and easily includes substructure rigid body modes. They studied the effect of truncation on the dynamic response of nonproportionally damped systems.

Martin and Ghlaim [28-29] considered problems in which components are connected through mechanical elements modeled by springs and viscous dampers; the problem is representative of an oil film. The damping problem is treated in first-order state-space form. The vibration characteristics of the components (using transfer matrix methods) and force equilibrium between components are used to form the system matrix. A typical problem involves two beams connected by springs and dashpots. Parametric studies relate retention of component modes to vibration characteristics of the system.

Gaul [30] studied the response of coupled systems consisting of a main structure attached to light substructures of few DOF and for structures connected by joints. Individual modal properties of the main structure and substructures are obtained; then system properties are found using the Raleigh and Rayleigh-Ritz procedures. Nonlinear joint behavior is modeled by an equivalent linearization based upon experimentally obtained hysteresis characteristics [31].

Tongue and Dowell [32] investigated a linear structure to which nonlinear substructures (springs, dashpots) were attached. A physical problem related to this system is an airplane with a linear fuselage and wing that contacts the ground through a nonlinear landing gear. The Lagrange multiplier method is used to determine the number of equations proportional to the number of system nonlinear constraints, rather than to the number of modes in the linear components. Steady-state and transient solutions are given for a cubic nonlinear spring element in the substructure.

A method that has been described for synthesis of damping factors and other modal data for a spacecraft in orbit is based on information at the component and substructure level [33]. The system equations are written in first-order state-space form. In a case study done for the Hermes spacecraft it was shown that modal damping ratios differed from in-orbit measured ratios by factors ranging from zero to five. The authors point out the need for additional documented case studies on practical systems to establish future and practical requirements for correlating synthesized and measured damping factors.

EXPERIMENTAL METHODS AND APPLICATIONS

Coppolino [34] has published an overview of combined experimental/analytical modeling with application to aerospace structures. He discusses modal truncation theory, determination of component modes from measured data, dynamic modeling, and instrumentation requirements. He describes problems encountered in practice (in comparison to purely analytical situations) for accurately describing component characteristics for an expendable launch vehicle system and for the space shuttle cargo system.

Martinez [35,36] used combined experimental/analytical modeling for an idealized beam structure with concentrated masses along its length and for a simplified shell payload system for an aerospace structure consisting of two large rigid masses connected by a thin-walled cylinder. The beam structure was cut into two substructures; properties of one substructure were determined entirely from tests. The data required are free-free frequencies and mode shapes including rotational DOF at the interface and translational and rotational residual flexibilities at the interface. Data were taken in the form of translational frequency response functions [FRF]. A finite element model was made of the entire substructure and for the entire beam. System modal frequencies were sensitive to errors in the subsystem description in the following order of importance: errors in modal frequency, rotational and translational mode shapes, and rotational and translational residual flexibility. The CMS model of the test payload makes use of free elastic modes, residual flexibility modes, and rigid body modes. It is possible to describe a CMS model without a detailed finite element model; in addition, the residual flexibilities are dependent on the stiffness of the payload flanges.

Chen and Cherng [37] considered a combined experimental/finite element approach for beam and plate structures. They used the Hurty-Craig-Bampton technique to describe the component modes. Rotational effects are approximated by reducing parallel force systems separated by a small distance to an equivalent force-couple

system. Measured experimental data were curve fitted by the methods of Ewins and Gleeson [38].

Another curve fitting method [39] is based on FRF for systems with light damping. A least squares technique was used on the experimentally determined FRF and its associated approximation for light damping.

Tsai and Palladino [40] used a similar least squares curve fitting technique to analyze the dynamics of a turbo-propeller engine. The components used in the analysis, the engine and nacelle structure, are coupled by springs representing elastomer connections. Another practical problem based on CMS techniques is the analysis of a machine tool spindle by Comparin and Houser [41]. The spindle assembly is modeled as shaft and housing substructures; connecting support bearings are modeled as springs and dashpots. Both experimental (FRF curve fits) and finite element methods were used in the study.

Modern large scale computer programs are an essential tool in these combined experimental/analytical techniques. For example, MSC/NASTRAN has been used [35,36]. Mei [42] used NASTRAN to perform modal synthesis; he used finite element techniques for truss and beam problems. Results are presented for the nonlinear vibration of a beam -- including effects of longitudinal deformation and inertia -- subject to harmonic excitation.

Shu and Chu [43] described generation of a superelement and its use in CMS. The superelement stiffness and mass matrices are obtained by using a group of finite elements. It is dynamically equivalent to the replaced substructure elements and behaves like a single finite element. This concept allows a modal synthesis analysis to be done within an existing finite element code, such as NASTRAN. An example is given of a deployable reflector system for a communications satellite.

REFERENCES

1. Craig, R.R. Structural Dynamics, Chapter 19, John Wiley & Sons (1981).

2. Meirovitch, L., Computational Methods in Structural Dynamics, Chapter 11, Sythoff and Noordhoff (1980).

3. Ewins, D.J., Modal Testing: Theory and Practice, Chapter 6, John Wiley & Sons (1984).

4. Craig, R.R., "Analytical Synthesis Techniques -- Overview," Combined Experimental/Analytical Modeling of Dynamic Structural Systems, ASME, AMD-Vol. 67, Section I, pp 1-30 (June 1985).

5. Ewins, D.J., "Modal Testing and Measurement -- Overview," Combined Experimental/Analytical Modeling of Dynamic Structural Systems, ASME, AMD-Vol. 67, Section I, pp 31-47 (June 1985).

6. Greif, R. and Wu, L., "Substructure Analysis of Vibration Systems," Shock Vib. Dig., 15 (1), pp 17-24 (Jan 1983).

7. Kuang, J.H. and Tsuei, Y.G., "A More General Method of Substructure Mode Synthesis for Dynamic Analysis," AIAA J., 23 (4), pp 618-623 (Nov 1983).

8. Kubomura, K., "A Theory of Substructure Modal Synthesis," J. Appl. Mech., Trans. ASME, 49, pp 903-909 (Dec 1982).

9. Curnier, A., "On Three Modal Synthesis Variants," J. Sound Vib., 90 (4), pp 527-540 (1983).

10. Sekimoto, S., "A Study on Truncation Error in Substructure Testing," 3rd IMAC, pp 1220-1226 (Jan 1985).

11. Shabana, Ahmed A. and Wehage, Roger A., "A Coordinate Reduction Technique for Dynamic Analysis of Spatial Substructures with Large Angular Rotations," J. Struc. Mech., 11 (3), pp 401-431 (1983).

12. Shabana, A.A., "Substructure Synthesis Methods for Dynamic Analysis of Multi-Body Systems," Computers Struc., 20 (4), pp 737-744 (1985).

13. Shabana, Ahmed, "Dynamics of Inertia Variant Flexible Systems Using Experimentally Identified Parameters," J. Mech., Transm. Automation Des. (Feb 1985).

14. Hale, A.L. and Meirovitch, L., "A General Substructure Synthesis Method for the Dynamic Simulation of Complex Structures," J. Sound Vib., 69 (2), pp 309-326 (1980).

15. Meirovitch, L. and Hale A.L., "On the Substructure Synthesis Method," AIAA J., 19 (7), pp 940-947 (July 1981).

16. Meirovitch, L. and Hale A.L., "A General Dynamic Synthesis for Structures with Discrete Substructures," J. Sound Vib., 85 (4), pp 445-457 (1982).

17. Hale, A.L. and Meirovitch, L., "A Procedure for Improving Discrete Substructure Representation in Dynamic Synthesis," AIAA J., 20 (8), pp 1128-1136 (Aug 1982).

18. Hale, A.L., "A Family of Subspace Iteration Algorithms for the Eigensolution of Large Structural Systems Composed of Substructures," Proc. 1st Intl. Modal Anal. Conf., pp 500-507 (Nov 1982).

19. Hale, A.L. and Warren, L.V., "Concepts of a General Substructuring System for Structural Dynamics Analyses," J. Vib. Acoust., Stress, Reliabil. Des., 107, pp 2-12 (Jan 1985).

20. Engels, R.C., "A Solution to the Craig/Bampton Eigenvalue Problem for Multi-Component Structures," 3rd IMAC, pp 299-304 (Jan 1985).

21. Matta, Kamal W., "Selection of Degrees of Freedom for Dynamic Analysis," ASME Paper No. 84-PVP-61.

22. Wilson, Edward L., Yuan, Ming-Wu, and Dickens, John M., "Dynamic Analysis by Direct Superposition of Ritz Vectors," Earthquake Engrg. Struc. Dynam., 10, pp 813-821 (1982).

23. Wilson, Edward L., "A New Method of Dynamic Analysis for Linear and Nonlinear Systems," Finite Elements Anal. Des., 1, pp 21-23 (1985).

24. Hale, A.L., "Substructure Synthesis and its Iterative Improvement for Large Nonconservative Vibratory Systems," AIAA J., 22 (2), pp 265-272 (Feb 1984).

25. Hale, A.L. and Bergman, L.A., "The Dynamic Synthesis of General Non-Conservative Structures from Separately Identified Substructure Models," J. Sound Vib., 98 (3), pp 431-446 (1985).

26. Wu, L. and Greif, R., "Substructuring and Modal Synthesis for Damped Structures," J. Sound Vib., 90 (3), pp 407-422 (1983).

27. Greif, R. and Wu, L., "Dynamic Response of Non-Proportionally Damped Systems Using a Successive Transformation Technique," 4th IMAC (Feb 1986).

28. Martin, K.F. and Ghlaim, K.H., "System Prediction Using Reduced Component Modes," 1st IMAC, pp 520-525 (Nov 1982).

29. Martin, K.F. and Ghlaim, K.H., "System Prediction by Reduction of Damped Component Modes," ASME Paper 85-DET-166.

30. Gaul, L., "Analytical and Experimental Study of the Dynamics of Structures with Joints and Attached Substructures," ASME 85-DET-164 (Sept 1985).

31. Gaul, L. and Bohlen, S., "Zum nichtlinearen Obertragungsverhalten von Fugestellen," ZAMM, 64 (4/5), pp T45-T48 (1984).

32. Tongue, B.H. and Dowell, E.H., "Component Mode Analysis of Nonlinear Nonconservative Systems," Trans. ASME, 50, pp 204-209 (Mar 1983).

33. Lips, K.W. and Vigneron, F.R., "Damping Synthesis for a Spacecraft Using Substructure and Component Data," AIAA-84-1053, (May 1984).

34. Coppolino, R.N., "Hybrid Experimental/Analytical Dynamic Models of Aerospace Structures," Combined Experimental/Analytical Modeling of Dynamic Structural Systems, ASME, AMD-Vol. 67, Section I, pp 79-107 (June 1985).

35. Martinez, D.R., Carne, T.G., Gregory, D.L. and Miller, A.K., "Combined Experimental/Analytical Modeling Using Component Mode Synthesis," Sandia Report, SAND83-1889 (Apr 1984).

36. Martinez, D.R., Miller, A.K., and Carne, T.G., "Combined Experimental/Analytical Modeling of Shell/Payload Structures," Combined Experimental/Analytical Modeling of Dynamic Structural Systems, ASME, AMD-Vol. 67, Section II, pp 167-194 (June 1985).

37. Chen, W.H. and Cherng, J.S., "Modal Synthesis via Combined Experimental and Finite Element Techniques with Consideration of Rotational Effects," J. Sound Vib., 103 (1), pp 1-11 (Aug 1983).

38. Ewins, D.J. and Gleeson, P.T., "A Method for Modal Identification of Lightly Damped Structures," J. Sound Vib., 84, pp 57-59 (1982).

39. Nagamatsu, A., Nakao, A., Iwawato, T., and Nagame, M., "Analysis of Vibration by Substructure Synthesis Method, Part 1," Bull. JSME, 26 (219), pp 1635-1640 (Sept 1983).

40. Tsai, G.C. and Palladino, J.A., "Application of the Component Synthesis with Least Squares Method to Achieve the Desired Frequencies and Mode Shapes," 2nd IMAC, pp 28-34 (Feb 1984).

41. Comparin, R. and Houser, D.R., "Experimental and Analytical Modeling of a Machine Tool Spindle Using Component Mode Synthesis," 2nd IMAC, pp 246-253 (Feb 1984).

42. Mei, Chuh, "Component Mode Synthesis and Large Deflection Vibrations of Complex Structures," NASA-CR-173338 (Feb 1984).

43. Shu, C.F. and Chu, F.H., "A General Superelement Approach by the Component Mode Synthesis Method," 2nd IMAC, pp 676-683 (Feb 1984).

LITERATURE REVIEW: survey and analysis of the Shock and Vibration literature

The monthly Literature Review, a subjective critique and summary of the literature, consists of two to four reviews each month, 3,000 to 4,000 words in length. The purpose of this section is to present a "digest" of literature over a period of three years. Planned by the Technical Editor, this section provides the **DIGEST** reader with up-to-date insights into current technology in more than 150 topic areas. Review articles include technical information from articles, reports, and unpublished proceedings. Each article also contains a minor tutorial of the technical area under discussion, a survey and evaluation of the new literature, and recommendations. Review articles are written by experts in the shock and vibration field.

WAVE PROPAGATION IN RANDOM COMPOSITE MATERIALS

A.I. Beltzer*

Abstract. This article reviews investigations of the dynamic response of random media since the late 1940s. Attention is focused on linear theory; elastic response of composite materials is emphasized. Work concerned with polycrystals, fluids, and fluid-saturated media or electromagnetic waves is included because this has influenced developments in the field of elastic behavior of composites.

Waves traveling in heterogeneous media are subject to multiple scattering. Constructive interference of disturbances creates a coherent wave that progresses in a certain direction. Because incoherent motions carry away part of the energy, even a conservative medium is seen by a coherent wave as an attenuative one. This specific type of energy loss gives rise to wave dispersion. The phenomenon may be further complicated by the presence of internal energy losses; for example, viscoelastic.

The propagation constant (wave number) k of a plane coherent wave is given by

$$k(\omega) = \omega/c(\omega) + i\alpha(\omega) \qquad (1)$$

where $c(\omega)$ and $\alpha(\omega)$ denote the phase velocity and attenuation; ω denotes circular frequency. The functions $c(\omega)$ and $\alpha(\omega)$ describe overall dynamic response; their definition in terms of composite microstructure has been the subject of theoretical and experimental investigations. An exposition of basic concepts is available [1]. Experiments [2-9] have shown a possibility of strong dispersion, depending on the ratio of wavelength to inclusion size.

BASIC THEORIES

A method has been based on the concept of configurational averaging and the quasi-crystalline approximation [10-22]. This approach assumes knowledge of a pair-correlation function of real materials, usually a difficult task. Extensive numerical works based on this method have been reported [23-27]. Perturbation techniques can be applied when nonhomogeneity is slight [28-34]. A heuristic method based on the concept of an effective scatterer has been used [35-46]. The idea resembles the coherent potential approximation. A variational procedure and related techniques have been developed and applied [47-55].

The above techniques can lead to results that violate the causality of the coherent wave. This might be a major drawback in the case of high-frequency or transient waves. A method has been established [56-63] in which basic features of the dispersion curves for the entire frequency interval have also been derived. These approaches have been applied to a variety of specific problems [64-78].

CONCLUSIONS

The dispersion and attenuation of elastic waves in random composites are characterized by the presence of three typical regions. They may be conveniently described in terms of the ratio of the wavelength λ to a typical inclusion size d.

$$\alpha(\omega) \cong O(\omega^4), \text{ when } \lambda/d \gg 1 \qquad (2)$$
(the Rayleigh region)

$$\alpha(\omega) \cong const, \text{ when } \lambda/d \ll 1 \qquad (3)$$
(the geometric limit)

In the intermediate region, $\lambda/d \cong O(1)$, the behavior of $\alpha(\omega)$ may show overshoots due to resonance scattering and strong attenuation. In extreme cases this causes a stopband when

$$c(\omega) \to \infty,$$

and no consistent signal may propagate through a medium [59,60]. The variation of phase velocity with frequency $c(\omega)$ obeys the bound

$$c_\infty = \lim_{\omega \to \infty} c(\omega) > c_0 = \lim_{\omega \to 0} c(\omega) \qquad (4)$$

where c_∞ describes in physical terms the propagation speed of a wideband pulse [59-77].

* Holon Center for Technological Education, Affiliated with Tel-Aviv University, P.O. Box 305, Holon 58102, Israel

REFERENCES

1. Ishimaru, A., Wave Propagation and Scattering in Random Media, Vols. 1 and 2, Academic Press, NY (1978).

2. Latiff, R.H. and Fiore, N.F., "Ultrasonic Attenuation and Velocity in Two-Phase Microstructures," J. Acoust. Soc. Amer., 57, pp 1441-1447 (1975).

3. Lefebre, J., Frohly, J., Torquet, R., Bruneel, C., and Rouvaen, J.M., "Experimental and Theoretical Study of the Multiple Scattering of Acoustical Waves in Inhomogeneous Media," Ultrasonics, 18, pp 170-174 (1980).

4. Kinra, V.K., Petraitis, M.S., and Datta, S.K., "Ultrasonic Wave Propagation in a Random Particulate Composite," Intl. J. Solids Struc., 16, pp 301-312 (1980).

5. Kinra, V.K. and Anand, A., "Wave Propagation in a Random Particulate Composite at Long and Short Wavelengths," Intl. J. Solids Struc., 18, pp 367-370 (1982).

6. Kinra, V.K., Ker, E., and Datta, S.K., "Influence of Particle Resonance on Wave Propagation in a Random Particulate Composite," Mech. Res. Comm., 9 (2), pp 109-114 (1982).

7. Davis, M.C., "Coal Slurry Diagnostics of Ultrasound Transmission," J. Acoust. Soc. Amer., 64, pp 406-411 (1978).

8. Davis, M.C., "Attenuation of Sound in Highly Concentrated Suspensions and Emulsions," J. Acoust. Soc. Amer., 65, pp 387-390 (1979).

9. Plona, T.J., "Observation of a Second Bulk Compressional Wave in a Porous Medium at Ultrasonic Frequencies," Appl. Phys. Lett., 36 (4), pp 259-261 (1980).

10. Foldy, L.L., "The Multiple Scattering of Waves", Phys. Rev., 67, pp 107-119 (1945).

11. Lax, M., "Multiple Scattering of Waves," Rev. Mod. Phys., 23, pp 287-310 (1951).

12. Lax, M., "Multiple Scattering of Waves, II: The Effective Field in Dense Systems," Phys. Rev., 85, pp 621-629 (1952).

13. Waterman, P.C. and Truell, R., "Multiple Scattering of Waves," J. Math. Phys., 2 (4), pp 512-537 (1961).

14. Fikioris, J.G. and Waterman, P.C., "Multiple Scattering of Waves II: Hole Correction in the Scalar Case," J. Math. Phys., 5 (10), pp 1413-1420 (1964).

15. Bose, S.K. and Mal, A.K., "Elastic Waves in a Fiber-Reinforced Composite," J. Mech. Phys. Solids, 22, pp 217-229 (1974).

16. Bose, S.K. and Mal, A.K., "Axial Shear Waves in a Medium with Randomly Distributed Cylinders," J. Acoust. Soc. Amer., 55 (3), pp 519-523 (1974).

17. Mal, A.K. and Bose, S.K., "Dynamic Elastic Moduli of a Suspension of Imperfectly Bonded Spheres," Proc. Camb. Phil. Soc., 76, pp 587-600 (1974).

18. Bose, S.K. and Mal, A.K., "The Elastic Moduli of a Fiber-Reinforced Composite," J. Appl. Mech., Trans. ASME, 99 (1), pp 61-67 (1977).

19. Twersky, V., "Coherent Scalar Field in Pair-Correlated Random Distributions of Aligned Scatterers," J. Math. Phys., 18, pp 2468-2486 (1977).

20. Twersky, V., "Acoustic Bulk Parameters in Distributions of Pair-Correlated Scatterers," J. Acoust. Soc. Amer., 64, pp 1710-1719 (1978).

21. Twersky, V., "Propagation and Attenuation in Composite Media," in: Lecture Notes in Physics, 154, Macroscopic Properties of Disordered Media, edited by R. Burridge, S. Childress, and G. Papanicolaou, Springer-Verlag, Berlin, pp 258-271 (1982).

22. Tsang, L., Kong, J.A., and Habashy, T., "Multiple Scattering of Acoustic Waves by Random Distribution of Discrete Spherical Scatterers with the Quasi-Crystalline and Percus-Yevick Approximations," J. Acoust. Soc. Amer., 71 (3), pp 552-558 (1982).

23. Sayers, C.M. and Smith, R.L., "Ultrasonic Velocity and Attenuation in an Epoxy Matrix Containing Lead Inclusions," J. Phys. D: Appl. Phys., 16, pp 1189-1194 (1983).

24. Varadan, V.K. and Varadan, V.V., "Frequency Dependence of Elastic (SH-) Wave Velocity and Attenuation in Anysotropic Two-Phase Media," Wave Motion, 1, pp 53-63 (1979).

25. Varadan, V.K., "Scattering of Elastic Waves by Randomly Distributed and Oriented Scatterers," J. Acoust. Soc. Amer., 65 (3), pp 655-667 (1979).

26. Varadan, V.K., Varadan, V.V., and Ma, Y., "Frequency-Dependent Elastic with a Random Distribution of Voids," J. Acoust. Soc. Amer., 76 (1), pp 296-300 (1984).

27. Varadan, V.K., Ma, Y., Varadan, V-V., "A Multiple Scattering Theory for Elastic Wave Propagation in Discrete Random Media," J. Acoust. Soc. Amer., 77 (2), pp 375-385 (1985).

28. Keller, J.B., "Stochastic Equations and Wave Propagation in Random Media," Proc. 16th Symp. Appl. Math., Amer. Math. Soc., NY, pp 145-179 (1964).

29. Stanke, F.E., and Kino, G.S., "A Unified Theory for Elastic Wave Propagation in Polycrystalline Materials," J. Acoust. Soc. Amer., 75 (3), pp 665-681 (1984).

30. McCoy, J.J., "On the Dynamic Response of Disordered Composites," J. Appl. Mech., Trans. ASME, pp 511-517 (1973).

31. Chow, T.S., "Scattering of Elastic Waves in an Inhomogeneous Solid," J. Acoust. Soc. Amer., 56 (4), pp 1049-1051 (1974).

32. Wensel, A.R., "Radiation and Attenuation of Waves in a Random Medium," J. Acoust. Soc. Amer., 71 (1), pp 26-35 (1982).

33. Wensel, A.R., "Radiation and Attenuation of Low- and High-Frequency Waves in a Random Medium," Wave Motion, 5, pp 215-223 (1983).

34. Wensel, A.R., "A Method for Analyzing Wave Propagation in Random Media," J. Acoust. Soc. Amer., 71 (2), pp 249-254 (1982).

35. Ament, W.S., "Wave Propagation in Suspensions," Naval Res. Lab. Tech. Rept., No. 5307, Washington DC (1959).

36. Urick, R.J. and Ament, W.S., "The Propagation of Sound in Composite Media," J. Acoust. Soc. Amer., 21 (2), pp 115-119 (1949).

37. Chaban, I.A., "Self-Consistent Field-Approach to the Calculation of the Effective Parameters of Micro-Inhomogeneous Media," Sov. Phys. Acoust., 10, pp 298-304 (1965).

38. Chaban, I.A., "Self-Consistent Field-Approach to the Calculation of the Effective Parameters of Micro-Inhomogeneous Media, II," Sov. Phys. Acoust., 11, pp 81-86 (1965).

39. Kuster, G.T. and Toksöz, M.N., "Velocity and Attenuation of Seismic Waves in Two-Phase Media," Geophys., 39, pp 587-618 (1974).

40. Kligman, R.L., Madigosky, W.M., Barlow, J.R., "Effective Dynamic Properties of Composite Viscoelastic Materials," J. Acoust. Soc. Amer., 70 (5), pp 1437-1444 (1981).

41. Gaunaurd, G.C. and Überall, H., "Resonance Theory of the Effective Properties of Perforated Solids," J. Acoust. Soc. Amer., 71 (2), pp 282-295 (1982).

42. Gaunaurd, G.C. and Überall, H., Erratum: "Resonance Theory of the Effective Properties of Perforated Solids," J. Acoust. Soc. Amer., 73 (1), p 372, (1983).

43. Gaunaurd, G.C. and Überall, H., "Resonance Effects and the Ultrasonic Effective Properties of Particulate Composites," J. Acoust. Soc. Amer., 74 (1), pp 305-313 (1983).

44. Gaunaurd, G. and Überall, H., "Resonance Theory of Bubbly Liquids," J. Acoust. Soc. Amer., 69, pp 362-370 (1981).

45. Berryman, J.G., "Long-Wavelength Propagation in Composite Elastic Media I. Spherical Inclusions," J. Acoust. Soc. Amer., 68 (6), pp 1809-1819 (1980).

46. Berryman, J.G. "Long-Wavelength Propagation in Composite Elastic Media II," J. Acoust Soc. Amer., 68 (6), pp 1820-1831 (1980).

47. Korringa, J. "Theory of Elastic Constants of Heterogeneous Media," J. Math. Phys., 14, pp 509-513 (1973).

48. Devaney, A.J. and Levine, H., "Effective Elastic Parameters of Random Composites," Appl. Phys. Lett., 37 (4), pp 377-379 (1980).

49. Devaney, A.J., "Multiple Scattering Theory for Discrete, Elastic, Random Media," J. Math. Phys., 21 (11), pp 2603-2611 (1980).

50. Willis, J.R., "A Polarization Approach to the Scattering of Elastic Waves -- I. Scattering by a Single Inclusion," J. Mech., Phys. Solids, 28, pp 287-305 (1980).

51. Willis, J.R., "A Polarization Approach to the Scattering of Elastic Waves -- II. Multiple Scattering from Inclusions," J. Mech., Phys. Solids, 28, pp 307-327 (1980).

52. Willis, J.R., "Variational and Related Methods for the Overall Properties of Composites, in Advances in Applied Mechanics," Yih, C.S. Ed., 21, pp 1-78, Academic Press, NY (1981).

53. Talbot, D.R.S. and Willis, J.R., "Variational Estimates for Dispersion and Attenuation of Waves in Random Composites -- I. General Theory", Intl. J. Solids Struc., 18 (8), pp 673-683 (1982).

54. Talbot, D.R.S. and Willis, J.R., "Variational Estimates for Dispersion and Attenuation of Waves in Random Composites -- II. Isotropic Composites," Intl. J. Solids Struc., 18 (8), pp 685-698 (1982).

55. Talbot, D.R.S. and Willis, J.R., "Variational Estimates for Dispersion and Attenuation of Waves in Random Composites --III. Fiber-Reinforced Materials," Intl. J. Solids Struc., 19 (9), pp 793-812 (1983).

56. Beltzer, A.I., "The Kramers-Kronig Relationships and Wave Propagation in Composites," J. Acoust. Soc. Amer., 73, pp 355-356 (1983).

57. Beltzer, A.I., Bert, C.W., and Striz, A.G., "On Wave Propagation in Random Particulate Composites," Intl. J. Solids Struc., 19 (9), pp 785-791 (1983).

58. Beltzer, A.I. and Brauner, N., "Waves of Arbitraty Frequency in Random Fibrous Composites," J. Acoust. Soc. Amer., 76 (3), pp 962-963 (1984).

59. Beltzer, A.I. and Brauner, N., "SH-Waves of an Arbitrary Frequency in Random Fibrous Composites Via the K-K Relations," J. Mech. Phys. Solids, 33 (5), pp 471-487 (1985).

60. Brauner, N. and Beltzer, A.I., "The Kramers-Kronig Relations Method and Wave Propagation in Porous Elastic Media," Intl. J. Engrg. Sci., 23 (11), pp 1151-1162 (1985).

61. Beltzer, A.I. and Brauner, N., "Elastic Waves Propagation in Polycrystalline Media: A Causal Response," Appl. Phys. Lett., 47 (10), pp 1054-1055 (1985).

62. Beltzer, A.I., "The High-Frequency Response of Random Elastic Composites," J. Appl. Math. Physics (ZAMP) 36, pp 921-926 (1985).

63. Beltzer, A.I., "Causality and the Keller Approximation for Acoustic Waves," J. Appl. Phys. (to appear).

64. Moon, F.C. and Mow, C.C., "Wave Propagation in a Composite Material Containing Dispersed Rigid Spherical Inclusions," RM-6139-PR, Rand, Santa Monica, CA (1970).

65. Sayers, C.M. and Smith, R.L., "The Propagation of Ultrasound in Porous Media," Ultrasonics," pp 201-205 (Sept 1982).

66. Sayers, C.M., "Ultrasonic Velocity Dispersion in Porous Materials," J. Phys. D: Appl. Phys., 14, pp 413-420 (1981).

67. Datta, S.K., "A Self-Consistent Approach to Multiple Scattering by Elastic Ellipsoidal Inclusions," J. Appl. Mech., Trans. ASME, pp 657-662 (1977).

68. Sayers, C.M., "On the Propagation of Ultrasound in Highly Concentrated Mixtures and Suspensions," J. Phys. D: Appl. Phys., 13, pp 179-184 (1980).

69. Sobczyk, K., "Elastic Wave Propagation in a Discrete Random Medium," Acta Mech., 25, pp 13-28 (1976).

70. Piau, M., "Attenuation of a Plane Compressional Wave by a Random Distribution of Thin Circular Cracks," Intl. J. Engrg. Sci., 17, pp 151-167 (1979).

71. Chatterjee, A.K., Mal, A.K., Knopoff, L., and Hudson, J.A., "Attenuation of Elastic Waves in a Cracked, Fluid-Saturated Solid," Math. Proc. Camb. Phil. Soc., 88, pp 547-561 (1980).

72. Mok, C.H., "Effective Dynamic Properties of a Fiber-Reinforced Material and the Propagation of Sinusoidal Waves," J. Acoust. Soc. Amer., 46 (3), pp 631-638 (1969).

73. Mal, A.K. and Knopoff, L., "Elastic Wave Velocities in Two Component Systems," J. Inst. Math. Appl., 3, pp 376-387 (1967).

74. Lloyd, P. and Berry, M.V., "Wave Propagation through an Assembly of Spheres," Proc. Phys. Soc., 91, pp 678-688 (1967).

75. Barrat, P.J., "Multiple Scattering of Plane Harmonic Elastic Waves in a Infinite Solid by an Arbitrary Configuration of Obstacles," Proc. Camb. Phil. Soc., 66, pp 469-480 (1969).

76. Junger, M.C., "Dilatational Waves in an Elastic Solid Containing Lined, Gas-filled Spherical Cavities," J. Acoust. Soc. Amer., 69 (6), pp 1573-1576 (1981).

77. Beltzer, A.I., "Causality and Wave Propagation in a Random Discrete Medium," Preprints 22, 22nd Ann. Mtg. Soc. Engrg. Sci., Pennsylvania State Univ., University Park (1985).

78. Beltzer, A.I. and Brauner, N. "Acoustic Waves in Random Discrete Media," J. Appl. Phys. (in print).

BOOK REVIEWS

ADVANCED DYNAMICS — MODELLING AND ANALYSIS

A.F. D'Souza and V.K. Garg
Prentice-Hall Inc., Englewood Cliffs, NJ
1984, 358 pages

This book develops mathematical models of dynamic systems that can be applied to the analysis of dynamic behavior and design synthesis. Most advanced books are written by physicists who are primarily interested in applying advanced dynamics to quantum mechanics and particle physics. Part I describes and illustrates principles of dynamics that can be used in deriving equations of motion. Part II encompasses a number of methods of analysis for investigating the dynamic behavior of engineering systems.

The book consists of nine chapters and three appendices. Part I includes the first five chapters. Chapter I introduces classic dynamics of particles and rigid bodies in terms of relativistic and nonrelativistic dynamics and inertial coordinates. A short discussion is given of Newtonian and Lagrangian dynamics. Chapter 2 on kinematics describes the inertial cartesian coordinate system including tangential, normal, polar, and cylindrical coordinates. Rotation of transformation of coordinates, rotating coordinate systems, and motion relative to the rotating Earth and motion in terms of transitory and rotating frames are described. The next chapter deals with dynamics of particles formulated by Newton's second law. Single particles and system of particles are mentioned in different coordinate systems; the principle of work energy and impulse momentum are discussed, as is the two-body problem.

Chapter 4 contains derivations of the equation of motion of a rigid body based on Newton's second law. The concluding section deals with application of the principles of work energy and impulse momentum to the dynamics of a rigid body. Gyroscopic motion is considered in terms of Euler's equations.

Chapter 5 focuses on Lagrangian dynamics -- a powerful approach involving direct application of Newton's laws to deriving the equations of motion. The concluding section contains an alternative approach using the Hamiltonian formulation. The generalized coordinates and moments are selected as a state variable so that the Lagrange equations can be represented as a set of first order equations.

Part II introduces the response of dynamic systems and discussed state-space formulation of the equations of motion, which are usually nonlinear; linearized equations of motion are regarded as perturbation from an equilibrium state. The concluding section covers a method applicable to computer solution of linear time-invariant systems involving a large number of degrees of freedom.

Chapter 7 considers three explicit methods -- central difference predictor, two-cycle iteration with trapezoidal rule, second of fourth-order Runge-Kutta methods -- and four implicit methods for dynamic response -- Houbolt, Wilson Theta, Newmark Beta, Park stiffly stable method. Each integration scheme calculates the response of a system with two degrees of freedom for different time steps. A sufficient number of time increments will show whether the scheme becomes unstable. The primary advantage of the Houbolt method is that it is unconditionally stable. The central difference and Park methods lag slightly in time expended. Methods stable for a linear example do not stay stable for nonlinear cases. The two-cycle iteration, Newmark Beta and Wilson Theta methods become unstable even when a small time step is used. The dynamic response from the fourth-order Runge-Kutta method is highly damped. The Houbolt, Park and central differences predictor methods indicate spurious stability characteristics for long time steps.

The next chapter reports on the dynamics of linear vibratory systems. Under certain circumstances the equations of motion for small displacement can be linearized in an equilibrium condition. A number of nonlinearities cannot be dealt with by frequency entrainment, jump phenomena, and limit cycle vibrations. Single-degree-of-freedom systems and multi-degree-of-freedom systems are described. Forced vibrations of damped systems are analyzed using the time domain method. Another method which uses the frequency response junction or matrix, is a frequency domain method. The chapter

concludes with a short discussion of the Bode diagram.

The last chapter deals with the stability of motion, especially in the sense of Lyapunov. Included are equilibrium states, stationary motion, and time varying motions. The three basic aspects of Lyapunov theory are stability, asymptotic stability, and instability. In the autonomous case, asymptotic stability and stability are always uniform. In the nonautonomous case, stability and uniform stability must be clarified. The authors also utilize a method for obtaining the stability of a nonlinear system. Perturbations are assumed to be small; the perturbation equation is linearized. When applicable, this method is recommended as an initial step for the autonomous system. Lyapunov's second or direct method investigates stability without solving the system equation.

This book requires careful and deliberate reading. The reviewer feels that a number of topics should have been included. The root locus method applied to vibration analysis is a natural for this book. The reviewer has found that the Hurwitz stability criteria is often superior to Routh's method. The reviewer further believes that vibration of beams and principle's plates should have been included, as should the Nyquist diagram, which is important in experimental modal analysis. Random vibration is not mentioned. A table of nomenclature would be welcome. In nonlinear analysis, the phase delta method is not mentioned. The book is recommended to those interested in dynamic systems and modeling.

H. Saunders
1 Arcadian Drive
Scotia, NY 12302

COUPLED NONLINEAR OSCILLATOR

Proceedings of the Joint U.S. Army-Center for Nonlinear Studies Workshop held in Los Alamos, NM, July 21-23, 1981

Edited by J. Chandra and A.C. Scott
North-Holland Publishing Company - Amsterdam
124 pages, 1983, $36.25

This volume contains nine papers dealing with various mathematical developments in nonlinear systems. Applications include nonlinear optics, laser technology, Josephson (superconductive) oscillators, hydrodynamic turbulence, and chemical and biological oscillators.

The first paper provides a brief analysis of weakly-coupled nonlinear oscillators with negative damping. These oscillators display transitions to quasi-periodic states, reverse bifurcations to phase-locked periodic states, and the possibility of competing stable phase-locked states. The second paper deals with a class of singularly perturbed delay differential equations that describes optical bistable devices. The paper examines chaotic behavior for certain parameters. The appearance of chaos in simple laser systems, which are regarded as nonlinear oscillators, is discussed in the third paper.

The fourth paper presents an analysis of the behavior of complex truncated Navier-Stokes equations. It is shown that, for Reynolds numbers below a certain critical threshold, every random initial point is captured first by one of N-dimensional hyperplanes then by an attractor on it. A fixed point can bifurcate into a closed curve consisting entirely of fixed points. In addition, a closed curve of fixed points can bifurcate into a torus covered entirely by either fixed points or periodic orbits. In the fifth paper the contact voltage in Josephson oscillators is determined with singular perturbation techniques. Expressions of contact voltage are determined for two resonance conditions. The sixth paper provides numerical and experimental investigations of a sine-Gordon model of the Josephson tunnel junction. The paper reports two distinct modes of soliton oscillations. The first is a bunched or congealed mode; the second is a symmetric mode.

The seventh paper examines nonlinear mutual coupling of radiation and molecules and the effects of spatial and temporal coupling of resonantly interacting radiation and matter. The results reveal a number of characteristics that belong to quasi-continuum. The authors of this paper claim that these characteristics are not well explained by either a purely discrete or a purely continuous model for the band of excited quantum states of the molecular vapor. The eighth paper deals with statistical analysis of long-term dynamic irregularity of a soluble quantum mechanical model known as the Jaynes-Cummings model. The analysis reveals that there exists a mean angular frequency that characterizes the oscillation when the initial photon distributions are coherent and chaotic. The partial recurrence frequencies of the atomic inversion are determined. An interesting feature observed by the authors is that when the oscillation time of the dynamical function is scaled according to the mean angular frequency and the amplitudes of oscillations are scaled by their root mean square value, the dynamical function

becomes completely independent of the mean photon number and the initial photon distribution. The last paper presents an investigation pertaining to molecular response characteristics and the effect of interrupted coarse-graining at an arbitrary time after photo excitation. The analysis can be applied to one of three cases: broad-band flash pumping of upper laser levels in some solid and liquid laser media, narrow-band laser excitation of fluorescence in low-temperature glasses, and laser-induced photo-excitation of dissociative or pre-dissociative levels in poly-atomic molecules.

The mathematical developments and applications presented in this workshop will be beneficial to researchers involved in nonlinear optics, super-conductive oscillators, and fluid mechanics. However, their impact on shock and vibrations problems is narrow.

R.A. Ibrahim
Texas Tech University
Department of Mechanical Engineering
Lubbock, Texas 79409

PREVIEWS OF MEETINGS

PROGRAM FOR INTERNATIONAL CONFERENCE ON ROTOR DYNAMICS

The IFToMM-JSME International Conference on Rotordynamics will be held in Tokyo on September 14-17, 1986. The official conference language is English. The technical program follows. For more information on Proceedings and Registration please contact:

Secretariat
ATTN: T. Nakajima
Japan Society of Mechanical Engineers
Sanshin-Hokusei Building, 4-9
Yoyogi 2-chome, Shibuya-ku
Tokyo, Japan
Telephone: (03) 379-6781
Telex: 2322493
Fax (03) 379-0934.

TECHNICAL PROGRAM

MONDAY

SEPTEMBER 15

Session A-I: Journal Bearing Dynamics (I)

The Calculation of the Stiffness and Damping Coefficients of Turbine Journal Bearings Considering Variable Viscosity
H.H. Ott and G. Paradissiadis

Analysis of Dynamic Characteristics for Cylindrical Journal Bearing Based on Average Flow Theory
K. Ono, *S. Michimura, and A. Tamura

The Lubrication of Multiple Ring Journal Bearing
A.E. Yousif

Dynamically Loaded Finite Length Journal Bearings with Bending of the Journal Within the Bearing
A.J. Smalley

Study on Dynamic Characteristics for Flexible Cylindrical Journal Bearing
*K. Ono and S. Michimura

A Study on the Dynamic Characteristics of Swing Pad Bearings
K. Iwamoto and Y. Hori

Session A-II: Journal Bearing Dynamics (II)

A Study on the Hybrid Bearing Characteristics for Large Pumps
*Y. Ozawa, H. Kanaki, and T. Kawakami

The Study on the Aerostatically Lubricated Bearings with Groove Compensation
*G. Lin, T. Aoyama and I. Inasaki

Temperature Pressure and Power Loss Measurements in an Offset Half Bearing
L.J. Read and *R.D. Flack

Application of Random Excitation Technique to Dynamic Characteristics Measurement of Bearing
*C. Yasuda, H. Kanki, Y. Ozawa, and T. Kawakami

A Method of Identifying Dynamic Support Stiffness of the Turbine Rotor and Bearing Dynamic Coefficients
W.H. Huang, *S.B. Xia and Z.G. Li

A Site Test of the Dynamical Characteristics of Fluid Film Bearings on a Running Power Turbine Set
H. Gong, H. Chang, *C. Chang, D. Jin and X. Tang

Session B-I: Theoretical Approach

The Singularity of the Riccati Transfer Matrix Method and a Method for Its Being Eliminated
Z. Wang

A 3-Dimensional Approach to Dynamic Analysis of Rotating Shaft-Disk Flexible Systems
M. Geradin and *N. Kill

Development of a Geometrically Non-Linear Timoshenko Beam Model for Application in Rotor Dynamics
T. Heeren, *B. de Kraker, M. Crooijmans, and D. van Campen

The Effect of Earth Rotation on the Dynamics of High-Speed Vertically Mounted Discs
*M.N. Sahinkaya and C.R. Burrows

* Speaker

Mechanics of Dynamically Tuned Gyro
D.M. Klimov

Session B-II: Balancing

The Role of Rigid Body Balancing for Flexible Rotating Shafts
A.G. Parkinson

A Method for Calculating the Optimum Balance Corrections of Flexible Rotors
D. Jin and X. Tang

Flexible Balancing of a Rotor With High Speed
Y. Nie and *H. Zhao

Adaptively Computer Controlled Automatic Balancing System
H. Kaliszer and M. Abdulwahab

Dynamic Balancing of Hydroelectric Generating Set
S.-X. Jiang

Dynamic Analysis and Field Balancing of 70MW Gas Turbine-Generators
E.J. Gunter and W.E. Gunter

Session C-I: Design Aspect

Concept of Unified Rotor Dynamic Analysis and Its Impact on Optimization and Engineering Productivity
*A.P. Singh

Computer Simulation of Torsional and Flexural Vibration in Machinery
*C. Troeder and A. Laschet

A New Approach to Describe the Mechanical Performance of Flexible Couplings in Drive Systems
*H. Peeken, C. Troeder, J. Benner, and W. Platt

The Development of a Rolling Piston Type Rotary Compressor of High Reliability at High Speed Operation (An Application of Rotor Vibration Analysis)
*M. Kubo, N. Kawashima and H. Marumo

Three Dimensional Stress Analysis on Rotor Shaft with Ribs Under Dynamic Load
T. Uchida, T. Murakami, K. Ishihara, K. Sonoda, N. Yamashita, and *H. Kanzaki

Composite Flywheel Optimization
*A.P. Bessonov and M.Y. Ochan

Session C-II: Measurement and System Identification

Hydraulic Force Estimation on Turbine Runners
*J.R.F. Arruda, F. Iguti and J.F. Vaqueiro

Measurement of Rotational Vibration of Gears Using Double Aperture Method
I. Hayashi and *T. Hayashi

A Fiber-Optic Interferometer for Measuring Vibration Inside an Operating Generator
R. Bernante, O. de Sanctis, *M. Martinelli, and A. Vallini

Balancing of Flexible Rotors by Modal Parameter Identification
Y. Kanemitsu

Identification of the Modal Parameters of a Rotor with the Strong Gyroscopic Effect by Perturbation Testing
D.E. Bently, *A. Muszynska, and A. Olas

Reliability Measures and Systems Identification
*O.P. Gandhi and V.P. Agrawal

TUESDAY

SEPTEMBER 16

Session A-III: Bearing Instability

Accurate Algebraic Approximation Formulas for the Threshold of Stability and the Critical Speed of a Flexible Overhung Rotor Bearing System
E.A. Muijderman

Sub-Synchronous Limit Cycles for a Flexible Shaft in Lobed Hydrodynamic Bearings
R.D. Brown

An Approximate Nonlinear Transient Analysis of Journal Bearing Response in Unstable Region of Linearized System
M. Malik and Y. Hori

Solving Non-Synchronous Vibration Problems of Large Rotating Machineries by Exciting Test in Actual Operating Condition
*H. Kanki, H. Fujii, A. Hizume, T. Ichimura, and T. Yamamoto

Vibrational Characteristics of a Rotor Shaft of a Electric Motor for Downhole Pump
Y. Hori, T. Kato, Y. Nishimura, and S. Konomoto

Analysis of Journal Bearings with Multiple Pressure Dams
P.E. Allaire and T. Okita

***Machine Dynamics in Terms of the System* Configuration Parameters**
*Z.A. Parszewski and J.M. Krodkiewski

Session A-IV: **Squeeze Film Damper and Foundation**

An Experimental Study of Squeeze Film Damper Bearing Without Centralizing Spring
*M. Tanaka and Y. Hori

The Unbalance Responses of a Rigid Rotor Supported in Squeeze-Film Damper Bearings
S. Chen and *J.-K. Xu

Vibration Control Capability of Squeeze-Film Bearings
F. Kaya

Rotor-Foundation (or Casing) Dynamics and Evaluation
*T. Inagaki and K. Shiraki

Detailed Experimental and Numerical Study of a Large Nuclear Steam Turbine Group
A. Pons

The Disturbing Force and Moment Analysis and the Dynamic Response Calculation of 'Die Forging Press' — 'Elastic Foundation' System
S. Liu, *Y. Dai, S. Gu, and W. Yao

Dynamic Analysis of Press-Elastic Foundation System Using Component Mode Synthesis
*S. Liu, S. Gu, and Y. Dai

Session B-III: **Blade Dynamics**

The Natural Frequencies of High Pressure Steam Turbine Blades
N.F. Rieger and T.C.T. Lam

Coupled Aerodynamic and Structural Aspects of Turbine Blading Aeroelasticity
S.S. Stecco and A. Arnone

Analytical and Experimental Investigation on Vibratory Stresses of a Rotating Steam Turbine Blade Under NPF Excitation
*J.S. Rao, K. Gupta, and N.S. Vyas

Transient Vibrations of Turbine Blades Due to Passage Through Partial Admission and Nozzle Excitation Resonances
H. Irretier

Study on Aerodynamic Force Exciting Vibration of Turbine Rotor Blade
A. Takehira, *M. Tanaka, K. Kuwata, A. Hoshino, H. Koike, K. Ishihara, T. Isozaki, *and H. Yamazaki*

Impeller Blade Vibration in Turbocharger
*N. Nishiwaki, K. Kimura and S. Shiratori

Session B-IV: **Torsional Vibration**

Start-Up Torsional Vibration of Rotating Machine Driven by Synchronous Motor
*T. Iwatsubo, Y. Yamamoto, and R. Kawai

Torsional System Design Relative to Synchronous Motor Start-Up with a Variable Frequency Power Supply System
P. de Choudhury

Improvement of a Reduced Torsional Model by Means of Parameter Identification
*P. Schwibinger, R. Nordmann, and T. Feng

Quick Predictions of Drive Conditions for Torsional Systems
B. Weyh

Analysis of Single Rotor Turbines by Means of Torsional Waves
*A. Mioduchowski and G.M. Faulkner

Noise of Lightly Loaded Gears
*I. Hayashi and T. Hayashi

In-Plane Circumferential Vibrations of Rotating Discs
S. Amada

Session C-III: **Diagnosis and Monitoring (I)**

Turbine Generator Vibration Monitoring in the CEGB
D.L. Thomas

A Diagnostic System to Define Malfunctioning Conditions of a Turbogenerator
*G. Diana, M. Gasparetto, F. Cheli, A. Manenti, and A. Vania

An On-Line Computer System for Phase-Angle Monitoring in Turbogenerator
J.-H. Wang

Identification of Fractures in Rotors
M.R. Kujath

An On-Line Crack Detection Method for Turbogenerator Rotors
*G. Diana, *N. Bachschmid, and F. Angeli*

Fault Diagnosis in Rotating Machinery
M.F. White

Session C-IV: Diagnosis and Monitoring (II)

A Study on Ball Bearing Fault Diagnosis by Cepstral Analysis
J.-E. Oh

An Investigation of the Early Detection of Defects in Ball Bearings Using Vibration Monitoring — Practical Limit of Detectability and Growth Speed of Defects
*T. Miyachi and K. Seki

Hilbert Transform Techniques in Machine Diagnostics
R.B. Randall

Session C-V: Active Control

Digital Control of Electro-Magnetic Damper for Rotating Machinery
*B. Nagai, Y. Okada, K. Matsuda, and K. Kibune

Flexible Rotor Vibration Analysis Combined with Active Magnetic Bearing Control
*O. Matsushita, M. Takagi, N. Tsumaki, M. Yoneyama, T. Sagaya, and H. Bleuler

Quasi-Modal Vibration Control by Means of Active Control Bearings
*K. Nonami and D.P. Fleming

On the Active Control of Rotors with Uncertain Parameters
*P.B. Hagedorn, K. Kelkel, and U. Weltin

Automatic Control of the Vibration of the Flexible Rotor with Microcomputer
G.-P. Feng

WEDNESDAY

SEPTEMBER 17, 1986

SESSION A-V: Instability

Whirling of a Flexible Cylinder Filled with Fluid
*S.H. Crandall and J. Mroszczyk

Vibration of Rotor Containing Liquid
*T. Shimogo, K. Yoshida, M. Kumagaya, and Y. Kazao

Unstable Vibration of a Truncated Conical Rotor with 16 Spiral Fins Partially Immersed in Water
F. Hara

Curing Self-Excited Vibrations in a Super-Critical Shaft
D. Thelen and *A.J. Giers

Self-Excited Vibrations of a Rotating Shaft with Internal Friction
H. Ota and *K. Mizutani

On the Rubbing Phenomena in Turbomachinery
A. Curami, *B. Pizzigoni, and A. Vania

Session A-VI: Instability (II)

Destabilization of Rotors from Friction in Internal Joints with Micro-Slip
J.W. Lund

Unstable and Forced Vibrations of an Asymmetrical Shaft Driven by a Universal Joint
H. Ota and *M. Kato

Lateral Vibration of Rotating Body Driven Through Constant-Velocity Joints
*M. Saigo and T. Iwatsubo

Investigations and Preventions of Self-Excited Torsional Vibration of Rotating Shafts Due to Slipping Clutch
S. Yanabe, A. Okada, *N. Yamagishi, A. Tonegawa, S. Ogawa and T. Ii

Some Theoretical Analyses on Flexible Rotor — Squeeze Film Damper Bearings System and Fluid Film Forces
*Z.-Q. Xue and G. Meng

System Vibrations: Rotor with Self-Excited Support
J. Awrejcewicz

Session B-V: Critical Speed and Forced Vibration (I)

Approximative Computation of Unbalance Vibrations of Multi-Bearing Rotors
E. Kramer

Influence of Slide Bearings and Support Dynamics in Rotor Dynamics
*H.F. Schwaberger and W.J. Keusch

Influence of Damped and Flexible Pedestals on the Dynamic Response of Flexible Rotors on Fluid Film Bearings
K.S. Ramakrishnan, *B.S. Prabhu, and B.V.A. Rao

Transient Vibration of Bladed Flexible Rotor Due to Sudden Imbalance
*M. Sakata, K. Kimura, H. Takahara, and H. Ohnabe

Some Practical Aspects on Rotor Dynamical Calculations
H. Alberg

Dynamics of Textile Spinning Spindles and Rotors
A. Kahraman, *M. Calskan and H.N. Ozguven

Session B-VI: Critical Speed and Forced Vibration (II)

Computer Study of Radial Vibrations in a Rotor/Ball Bearing System
*H. Tamura, E.H. Gad, and A. Sueoka

A Computer Programme for Determination of the Natural Frequencies of Multilayer Rotors-Shells
L. Papa and *E. Campana

The Study of Mechanical Model of Shrink Fit Rotor
W. Zhang, S. Xia, F. Chun, C. Wu, G. Wang, and Q. Zhang

On a Nature and Some Properties of Insensitive Speeds of a Flexible Rotor
A.A. Gusarov

Dynamic Characteristics of the Rotors with Axial Vibration
B.C. Wen and D. Liu

Degeneration of the Free Vibration Frequency of the Crafts Loaded by Torsional Moment
A.J. Poplawski

Session C-VI: Seal Dynamics (I)

Labyrinth Seal Analysis for Centrifugal Compressor Design — Theory and Practice
R.G. Kirk

A Theoretical Approach to Labyrinth Seal Forces — Lateral Forces of the Labyrinth Seal on a Whirling Rotor
*T. Kameoka, M. Kurohashi, T. Fujikawa, and T. Abe

Theoretical and Experimental Study on the Destabilizing Force by Labyrinth Seal
H. Kanki, *S. Morii and A. Hizume

Testing for Rotordynamic Coefficients and Leakage: Circumferentially Grooved Turbulent Annular Seals
*D.W. Childs, C.-H. Kim

Rotordynamic Coefficients and Leakage Flow for Straight and Grooved Seals in Turbopumps
*R. Nordmann, F.J. Dietzen, A. Frei, and S. Florjancic

The Effects of Surface Waviness and Roughness on Seal Dynamics
T. Iwatsubo and *B.S. Yang

Session C-VII: Seal Dynamics (II)

Steam Excited Vibration in Rotor-Bearing System
S. Hisa, *H. Sakakida, S. Asatsu, and T. Sakamoto

Fluid Force Testing Machine for Whirling Centrifugal Impeller
H. Ohashi

Fluid Effects on Rotor Dynamics of Hydraulic Turbomachines
R. Liebe

Effect of Seals on Rotor Dynamic
*M. Falco and G. Mimmi

Effect of Fluid Film Seals on the Stability of Turbocompressor Rotor
M. Tanaka, S. Sugimura, *J. Mitsui and A. Nishidoi

Dynamical Stability of Gas Sealing in Turbo-Machinery
O. Mahrenholtz

SHORT COURSES

AUGUST

DESIGN AND ANALYSIS OF ENGINEERING EXPERIMENTS
Dates: August 4-15, 1986
Place: Ann Arbor, Michigan
Objective: Recent developments in the field of testing, methods for designing experiments, interpretation of test data, and better utilization of the existing data. Design of experiments with a small number of test pieces or runs with high dispersion is emphasized. Obtaining maximum information from limited test data is stressed.

Contact: William J. Anderson, Engineering Summer Conferences, 200 Chrysler Center, North Campus, The University of Michigan, Ann Arbor, MI 48109 - (313) 764-8490.

RANDOM VIBRATION IN PERSPECTIVE — AN INTRODUCTION TO RANDOM VIBRATION AND SHOCK, TESTING, MEASUREMENT, ANALYSIS, AND CALIBRATION, WITH EMPHASIS ON STRESS SCREENING
Dates: August 18-22, 1986
Place: Santa Barbara, California
Dates: October 6-10, 1986
Place: Boston, Massachusetts
Dates: November 3-7, 1986
Place: Orlando, Florida
Dates: February 2-6, 1987
Place: Santa Barbara, CA
Dates: March 9-13, 1987
Place: Washington, D.C.
Objective: To show the superiority (for most applications) of random over the older sine vibration testing. Topics include resonance, accelerometer selection, fragility, shaker types, fixture design and fabrication, acceleration/power spectral density measurement, analog vs digital controls, environmental stress screening (ESS) of electronics production, acoustic (intense noise) testing, shock measurement and testing. This course will concentrate on equipment and techniques, rather than on mathematics and theory. The 1984 text, "Random Vibration in Perspective," by Tustin and Mercado, will be used.

Contact: Wayne Tustin, 22 East Los Olivos St., Santa Barbara, CA 93105 - (805) 682-7171.

MACHINERY VIBRATION ANALYSIS I
Dates: August 19-22, 1986
Place: New Orleans, Louisiana
Dates: November 11-14, 1986
Place: Chicago, Illinois
Objective: This course emphasizes the role of vibrations in mechanical equipment instrumentation for vibration measurement, techniques for vibration analysis and control, and vibration correction and criteria. Examples and case histories from actual vibration problems in the petroleum, process, chemical, power, paper, and pharmaceutical industries are used to illustrate techniques. Participants have the opportunity to become familiar with these techniques during the workshops. Lecture topics include: spectrum, time domain, modal, and orbital analysis; determination of natural frequency, resonance, and critical speed; vibration analysis of specific mechanical components, equipment, and equipment trains; identification of machine forces and frequencies; basic rotor dynamics including fluid-film bearing characteristics, instabilities, and response to mass unbalance; vibration correction including balancing; vibration control including isolation and damping of installed equipment; selection and use of instrumentation; equipment evaluation techniques; shop testing; and plant predictive and preventive maintenance. This course will be of interest to plant engineers and technicians who must identify and correct faults in machinery.

Contact: Dr. Ronald L. Eshleman, Director, The Vibration Institute, 101 West 55th Street, Suite 206, Clarendon Hills, IL 60514 - (312) 654-2254.

VIBRATIONS OF RECIPROCATING MACHINERY
Dates: August 19-22, 1986
Place: New Orleans, Louisiana
Objective: This course on vibrations of reciprocating machinery includes piping and foundations. Equipment that will be addressed includes reciprocating compressors and pumps as well as engines of all types. Engineering problems will be discussed from the point of view of compu-

tation and measurement. Basic pulsation theory --including pulsations in reciprocating compressors and piping systems -- will be described. Acoustic resonance phenomena and digital acoustic simulation in piping will be reviewed. Calculations of piping vibration and stress will be illustrated with examples and case histories. Torsional vibrations of systems containing engines and pumps, compressors, and generators, including gearboxes and fluid drives, will be covered. Factors that should be considered during the design and analysis of foundations for engines and compressors will be discussed. Practical aspects of the vibrations of reciprocating machinery will be emphasized. Case histories and examples will be presented to illustrate techniques.

Contact: Dr. Ronald L. Eshleman, Director, The Vibration Institute, 101 West 55th Street, Suite 206, Clarendon Hills, IL 60514 - (312) 654-2254.

SEPTEMBER

TIME DOMAIN MODAL VIBRATION TESTING TECHNIQUE

Dates: September 8-9, 1986
Place: Virginia Beach, Virginia
Objective: The seminar presents an in-depth study of the ITD method, examining results of previous applications and the applied use of the computer program and its selected options. Through attendance at the workshop, participants will receive the complete computer program of the ITD method and should be able to use the technique in modal vibration testing applications.

Contact: W.C. Bentley, Industrial Programs, School of Engineering, Old Dominion University, Norfolk, VA 23508 - (804) 440-4243

VIBRATION DAMPING TECHNOLOGY

Dates: September 15-19, 1986
Place: Dayton, Ohio
Dates: January, 1987
Place: Clearwater, Florida
Objective: Basics of theory and application of viscoelastic and other damping techniques for vibration control. The courses will concentrate on behavior of damping materials and their effect on response of damped systems, linear and nonlinear, and emphasize learning through small group exercises. Attendance will be strictly limited to ensure individual attention.
Contact: David I. Jones, Damping Technology Information Services, Box 565, Centerville Branch USPO, Dayton, OH 45459-9998 - (513) 434-6893.

GEAR NOISE

Dates: September 17-19, 1986
Place: The Ohio State University
Objective: The course will cover general noise measurements and analysis, causes of gear noise, gear noise reduction techniques, dynamic modeling, gear noise signal analysis, and modal analysis of gear boxes. Problems of course attendees will be discussed in special workshop sessions. Laboratory demonstrations will also be given. Featured speakers will be mr. Donald Welbourn formerly of The University of Cambridge, and Professors D.R. Houser and R. Singh of The Gear Dynamics and Gear Noise Research Laboratory at The Ohio State University.

Contact: Mr. Richard D. Frasher, Director, Continuing Education, College of Engineering, 2070 Neil Avenue, Columbus, Ohio 43210, (614) 422-8143

OCTOBER

1986 JOHN C. SNOWDON VIBRATION CONTROL SHORT COURSE

Dates: October 20-24, 1986
Place: The Pennsylvania State University
Objective: This course, under the sponsorship of the Applied Research Laboratory, is presented by internationally known lecturers. It was initiated by the late Professor John C. Snowdon a decade ago and now continues under the guidance of Dr. Eric E. Ungar of Bolt Baranek and Newman, Inc. The course emphasizes principles, general approaches and new developments, with the aim of providing participants with efficient tools for dealing with their own practical vibration problems.

Contact: Gretchen A. Leathers, 410 Keller Conference Center, University Park, PA 16802 - (814) 863-4563

ABSTRACT CONTENTS

MECHANICAL SYSTEMS 28
- Rotating Machines 28
- Reciprocating Machines 29
- Power Transmission Systems 30
- Metal Working and Forming 30
- Isolation and Absorption 30

STRUCTURAL SYSTEMS 31
- Bridges 31
- Buildings 31
- Foundations 33
- Harbors and Dams 35
- Off-shore Structures 38

VEHICLE SYSTEMS 36
- Ground Vehicles 36
- Missiles and Spacecraft 36

MECHANICAL COMPONENTS 36
- Absorbers and Isolators 36
- Bearings 36
- Gears 38
- Fasteners 38
- Seals 39

STRUCTURAL COMPONENTS 39
- Cables 39
- Bars and Rods 40
- Cylinders 42
- Frames and Arches 43
- Membranes, Films, and Webs 43
- Plates 43
- Shells 46
- Rings 48
- Pipes and Tubes 49
- Ducts 49

DYNAMIC ENVIRONMENT 50
- Acoustic Excitation 50
- Shock Excitation 52
- Vibration Excitation 54

MECHANICAL PROPERTIES 55
- Damping 55
- Fatigue 57
- Elasticity and Plasticity 57

EXPERIMENTATION 58
- Measurement and Analysis 58
- Dynamic Tests 59
- Diagnostics 60
- Balancing 60

ANALYSIS AND DESIGN 62
- Analytical Methods 62
- Parameter Identification 63
- Design Techniques 63

AVAILABILITY OF PUBLICATIONS ABSTRACTED

None of the publications are available at SVIC or at the Vibration Institute, except those generated by either organization.

Periodical articles, society papers, and papers presented at conferences may be obtained at the Engineering Societies Library, 345 East 47th Street, New York, NY 10017; or Library of Congress, Washington, D.C., when not available in local or company libraries.

Government reports may be purchased from National Technical Information Service, Springfield, VA 22161. They are identified at the end of bibliographic citation by an NTIS order number with prefixes such as AD, N, NTIS, PB, DE, NUREG, DOE, and ERATL.

Ph.D. dissertations are identified by a DA order number and are available from University Microfilms International, Dissertation Copies, P.O. Box 1764, Ann Arbor, MI 48108.

U.S. patents and patent applications may be ordered by patent or patent application number from Commissioner of Patents, Washington, D.C. 20231.

Chinese publications, identified by a CSTA order number, are available in Chinese or English translation from International Information Service, Ltd., P.O. Box 24683, ABD Post Office, Hong Kong.

Institution of Mechanical Engineers publications are available in U.S.: SAE Customer Service, Dept. 676, 400 Commonwealth Drive, Warrendale, PA 15096, by quoting the SAE-MEP number.

When ordering, the pertinent order number should always be included, not the **DIGEST** abstract number.

A List of Periodicals Scanned is published in issues, 1, 6, and 12.

MECHANICAL SYSTEMS

ROTATING MACHINES

86-1358
Investigation of Torsional Vibration and Torque of Synchronous Motor Drives (Untersuchung der Torsionsschwingungen und Drehmomentenverläufe von Antriebssystemen mit Synchronmotoren)
B. Oswald, K. Geyer
TU Dresden, Elektroenergietechnik
Maschinenbautechnik, 34 (10), pp 451-455 (1985)
7 figs, 2 tables, 2 refs (in German)

KEY WORDS: Synchronous motors, Torsional vibrations

Synchronous motors cause oscillating torques with double-slip frequency. It can result in torsional oscillations on startup. A differential equation system of state is set up for uniform describing dynamic behavior of masses and windings and is solved by numerical integration. The calculated courses of torque and speed are stated and discussed.

86-1359
General Linear and Nonlinear Torsional Vibration in Rotor Systems
F.R. Soares
Ph.D. Thesis, Case Western Reserve Univ., 366 pp (1985) DA8525238

KEY WORDS: Rotors, Torsional vibrations, Computer programs, Finite element technique

A general purpose rotor torsional vibrations computer code has been developed (STORV). This code embodies the state-of-the-art capability plus new developments not presently available in computer codes for torsional vibrations analysis and simulation. Accurate modeling of the rotor system including nonlinearities and component interactions and the development of algorithms to determine the total system dynamic response is provided. The finite element method (FEM) is the basic modeling technique. Parametric analysis of the rotor torsional dynamics with gear sets having tooth gear error is included. The STORV code is configured to efficiently handle a wide range of specific problem and analysis types.

86-1360
Proof Tests for Rotor-Dynamics Software
R.J. Iannuzzelli
Sperry Corp., Blue Bell, PA
Mach. Des., 57 (28), pp 115-121 (Dec 12, 1985)

KEY WORDS: Rotors, Computer programs

A set of test cases that can be used to verify the accuracy of a rotor-dynamics software package before you is described.

86-1361
Stability of Limit Cycles in Frictionally Damped and Aerodynamically Unstable Rotor Stages
A. Sinha, J.H. Griffin
The Pennsylvania State Univ., University Park, PA
J. Sound Vib., 103 (3), pp 341-356 (Dec 8, 1985)
4 figs, 4 tables, 14 refs

KEY WORDS: Rotors, Flutter, Coulomb friction, Bladed disks

This paper deals with the stability of limit cycles (Steady-State Oscillations) associated with the multi-degree-of-freedom model of a frictionally damped and aerodynamically unstable rotor stage. By using the first order averaging technique, a generalized criterion has been established to sort out those unstable limit cycles which govern the maximum transient amplitude beyond which the rotor stage becomes unstable. The stability of the remaining steady-state solutions is analyzed by linearizing the averaged system of differential equations. Numerical results are discussed for three-, four-, and five-bladed disks.

86-1362
Consistent Matrices in Rotor Dynamics
G. Genta
Politecnico di Torino, Italy
Meccanica, 20 (3), pp 235-248 (Sept 1985) 5 figs, 5 tables, 22 refs

KEY WORDS: Rotors, Rotatory inertia effects, Transverse shear deformation effects, Matrix methods

The expressions for the consistent mass and gyroscopic matrices for a constant section shaft element are obtained taking into account both shear deformation and transversal inertia. The results are compared with closed form solutions, which are available in simple cases. The results obtained show that the study of the dynamic behavior of the rotor with a model which includes rotational inertia but not shear deformation is, at least in the case examined, misleading. Formulae for matrix condensation

and for taking into account the effects of axial load and of a linear unbalance distribution are given. Damped systems can be studied using the same model, provided that damping can be assumed to be of either viscous or hysteretic type.

86-1363
Structural Reliability of a Marine Diesel Engine Propulsion Shafting System
E. Nikolaidis
Ph.D. Thesis, The Univ. of Michigan, 190 pp (1985) DA8520956

KEY WORDS: Shafts, Diesel engines, Marine engines, Torsional vibrations, Fatigue life

A method for estimating the reliability of the propulsion shafting system of a diesel ship is presented. Probabilistic modeling of the diesel engine and the propeller torsional excitations; determinations of the statistical properties of the torsional vibratory stress amplitude at any point on the shaft; analysis of first excursion and fatigue failure modes; and estimation of each shafting segment failure probability. Examples using an existing propulsion shafting system are presented. It is shown that the requirement of a high value for the traditional safety factor does not always ensure that the system is safe. Significant critical speeds that cannot be identified by the traditional deterministic analysis are revealed when the probabilistic method is applied. Furthermore, the shafting segments most likely to fail are different from the segments with the higher mean stress as determined by the traditional deterministic analysis. The reliability based analysis is more realistic and provides a better measure of structural safety to the designer than the traditional deterministic analysis.

86-1364
Eliminate Machinery Vibration by Correcting Shaft Misalignment
J. Piotrowski
General Electric Aircraft Engine Business Group, Evendale, OH
Mech. Engrg., 108 (2), pp 80-86 (Feb 1986) 12 figs

KEY WORDS: Shafts, Alignment, Graphic methods

A graphic alignment technique is described for measuring and correcting shaft misalignment.

86-1365
Asynchronous Instability of a Rotating Centrifuge Partially Filled with Fluid
C.A. Cheng, A.S. Berman, T.S. Lundgren
Univ. of Minnesota, Minneapolis, MN
J. Appl. Mech., 52 (4), pp 777-782 (Dec 1985) 11 figs, 7 refs

KEY WORDS: Centrifuges, Whirling, Fluid-filled containers, Elastic supports

An experimental investigation of the asynchronous whirl motion of a partially filled rotating centrifuge on an elastic support system has been performed. Whirl runout amplitudes are measured and the data are used to deduce the stability boundaries of the asynchronous whirl. The effects of various parameters on the stability boundaries are studied systematically. These parameters are the fill ratio, mass ratio, Reynolds number, and the damping of the elastic support system. The experimental results are compared with theoretical predictions based on a linear analysis. Free surface shapes are compared with results of nonlinear analysis.

86-1366
Rotor Instability in Centrifugal Pumps
D. France
Weir Pumps, Ltd., Glasgow, Scotland
Shock Vib. Dig., 18 (1), pp 9-13 (Jan 1986) 3 figs, 21 refs

KEY WORDS: Centrifugal pumps, Subsynchronous vibration

The literature describing rotor instability phenomena in centrifugal pumps is reviewed. Discussion is confined to subsynchronous instabilities classified according to origin and in terms of the fractional frequency ratio of occurrence. When possible, the underlying mechanisms of the instabilities are described.

RECIPROCATING MACHINES

86-1367
Directive VDI 2063: Measurement and Evaluation of Mechanical Vibrations of Reciprocating Engines and Reciprocating Compressors (Richtlinie VDI 2063: Messung und Beurteilung mechanischer Schwingungen von Hubkolbenmotoren und-kompressoren)

Konstruktion, 37 (9), pp A29-A30 (Sept 1985), 37 (10), pp A43-A44 (Oct 1985), 37 (11) (Nov 1980) (in German)

KEY WORDS: Reciprocating engines, Reciprocating compressors, Translational response, Standards and codes

The directive, described in the three issues, deals with permissible translational vibration of reciprocating machinery. It was published in 1985 in German and in English.

POWER TRANSMISSION SYSTEMS

86-1368
Transmission Acoustic Vibration Testing
C. Yoerkie, A. Chory
United Technologies Corp., Stratford, CT
Rept. No. USAAVRADCOM-TR-83-D-34, 85 pp (July 1985) AD-A159 022/3/GAR

KEY WORDS: Power transmission systems, Helicopters, Vibration signatures

Laboratory tests were conducted to determine individual and combined effects of a high contact ratio (HCR) planetary gearset and a stainless steel housing on the acoustic (high frequency) vibration signature of the BLACK HAWK helicopter main transmission. Vibration levels at the planetary mesh frequency increased significantly with the stainless steel housing, but increased unexpectedly with the HCR planetary. The primary reason for the increased response with the HCR was the reduced gear face widths.

METAL WORKING AND FORMING

86-1369
The Effect of Non-Uniform Insert Pitch on Noise Generation During Face Milling Operations
T.N. Moore
Ph.D. Thesis, Univ. of Windsor, Canada, (1985)

KEY WORDS: Metal working, Work pieces, Modal analysis, Noise generation

To better understand the structural response of the workpiece a complete modal analysis is performed. In addition, noise frequency response functions are generated and are shown to form a basis on which to predict the noise radiation characteristics of the workpiece. A hybrid digital-analog computing system is developed and used to simulate the workpiece response and to demonstrate the influence of various parameters such as forcing function definition, natural frequency, damping, and width of cut on system response. A more realistic forcing function definition, than the often used force impulse model, is developed. It is subsequently shown that significant differences in workpiece response occur for excitations based on these two models. It is also demonstrated that variation in width of cut has a significant influence on the forcing function definition.

86-1370
A Dynamic Modeling Approach to the Optimal Design of Nonuniform Chip Loading in Face Milling
Hao-Jen Fu
Ph.D. Thesis, Univ. of Illinois at Urbana-Champaign, 247 pp (1985) DA8521766

KEY WORDS: Milling (machining), Optimum design

Recent industrial demands on improved quality and productivity have increased the need for analytically sound tools for design, planning, optimization and control of complex manufacturing systems. In this thesis, the improvement of the dynamic performance of the multi-tooth face milling process is studied. The chip loading pattern is considered as the design parameter, and the consequences of nonuniform chip loading obtained by uneven insert spacing design and varying spindle speed design are investigated. The dynamic system performance is evaluated through force characteristics and associated vibrations, either forced or the chatter condition.

ISOLATION AND ABSORPTION

86-1371
Conveying by External Vibrators (Fordern mit AuBenvibratoren)
U. Kaatzsch, U. Geiling
VEB Baustoffmaschinen Ludwigslust
Maschinenbautechnik, 34 (10), pp 461-463 (1985)
6 figs, 3 refs (in German)

KEY WORDS: Vibrators, Materials handling equipment

The article presents briefly the applications of vibratory conveyors and various drives. External vibrators are discussed in particular. After describing how to select suitable vibration frequencies for the new generation external vibrators, simplified calculation methods are given for the design of a simple vibratory conveyor.

STRUCTURAL SYSTEMS

BRIDGES

86-1372
Nonlinear Earthquake Analysis of Wall Pier Bridges
C.A. Issa
Ph.D. Thesis, Virginia Polytechnic Inst. and State Univ., 142 pp (1985) DA8521322

KEY WORDS: Bridges, Seismic response, Walls, Plates

Accurately predicting the response of complex bridge structures to strong earthquake ground motion requires the use of sophisticated nonlinear dynamic analysis computer programs. They are not generally available to the bridge design engineer. The analytical tools that have been developed are generally applicable to bridges whose substructures can be idealized as beam-columns. Bridges with wall piers do not belong to this category. The major objective of this study is to develop an analysis tool capable of simulating the effects of earthquakes on monolithic concrete wall pier bridges.

BUILDINGS

86-1373
Optimal Design of a 3-D Reinforced Concrete and Steel Buildings Subjected to Static and Seismic Loads
K.Z. Truman
Ph.D. Thesis, Univ. of Missouri-Rolla, 414 pp (1985) DA8525427

KEY WORDS: Buildings, Reinforced concrete, Steel, Seismic design, Optimization

A structural optimization algorithm based upon an optimality criteria approach is presented for three-dimensional statically and dynamically loaded steel and/or concrete structures. The theoretical work is presented in terms of scaling, sensitivity analyses, optimality criteria, and Lagrange multiplier determination. The structures can be subjected to a combination of static and/or dynamic displacement and stress, and natural frequency constraints.

86-1374
The Responses of a Building on Sliding Pads to Two Earthquake Models
T. Noguchi
Kyoto Univ., Kyoto, Japan
J. Sound Vib., 103 (3), pp 437-442 (Dec 8, 1985) 3 figs, 4 refs

KEY WORDS: Buildings, Base isolation, Seismic isolation, Equivalent linearization method

The equivalent linearization procedure has established that a mass-dashpot system can be used as a simple model for considering seismic isolation of buildings on sliding pads. In this paper, expressions are developed for time-dependent mean-square responses of the dashpot system to two earthquake models.

86-1375
Seismic Risk Analysis of a Multi-Site Portfolio of Buildings
T.A. Sabol
Ph.D. Thesis, Univ. of California, Los Angeles, 174 pp (1985) DA8522332

KEY WORDS: Buildings, Earthquake damage, Damage prediction

This dissertation develops a seismic risk assessment methodology for a multi-site portfolio of buildings that considers the probabilistic nature of seismic loading and seismic damage. The relative contributions of individual buildings to the total seismic risk of the portfolio, and the amount of damage correlation between individual buildings in the portfolio are covered. The method is implemented using a series of computer simulations to generate simulated earthquake intensities based on the recurrence relationships and to perform the required optimizations. An illustrative example is presented.

86-1376
Earthquake Design Compared to Measured Response
J.K. Wight

Univ. of Michigan, Ann Arbor, MI
ASCE J. Struc. Engrg., 112 (1), pp 149-164 (Jan 1986) 9 figs, 7 tables, 10 refs

KEY WORDS: Buildings, Reinforced concrete, Seismic design, Experimental data, Seismic response

The design of a full-scale reinforced concrete building is compared to US seismic resistant design practice. The observed behavior and measured response of the building during a series of simulated earthquake tests is compared to behavior predicted by US engineers. The test structure is the seven story building tested in Japan as part of the US-Japan cooperative research agreement.

86-1377
Free Vibrations of Steel Mill Buildings
M.E. Liebler, G.D. Manolis
State Univ. of New York at Buffalo, NY
Engrg. Struc., 7 (4), pp 253-262 (Oct 1985) 6 figs, 5 tables, 14 refs

KEY WORDS: Buildings, Industrial facilities, Influence coefficient method, Dynamic stiffness, Finite element technique

The vibration characteristics of steel mill buildings designed according to standard specifications are investigated. The dynamic stiffness influence coefficient method is used in deriving a simple, yet rigorous, method of extraction of the first few planar horizontal and vertical natural frequencies and modal shapes. The advantage of this method is that the final system matrix is only of rank two. The finite element method is used for the complete three-dimensional representation of a typical steel mill building with an overhead crane at two different positions. In all cases, the representation of real structures by idealized mathematical models is meticulously performed in order to ensure that all salient structural features are correctly included. It is concluded that the two-dimensional representations yield natural frequencies and modal shapes that are in good agreement with the corresponding ones obtained from complete three-dimensional representations.

86-1378
Wind-induced Motion of Tall Buildings
A. Tallin, B. Ellingwood
Polytechnic Institute of New York, NY
Engrg. Struc., 7 (4), pp 245-252 (Oct 1985) 11 figs, 4 tables, 19 refs

KEY WORDS: Buildings, Wind-induced excitation, Random vibrations

Modern buildings designed such that their lateral drifts under statically applied wind loads are less than some fraction of building height, may vibrate excessively during winds and cause occupant discomfort. Methods are presented for evaluating the vibration characteristics of buildings using random vibration theory to relate the fluctuating wind forces to structural response. These methods can be used to evaluate serviceability or to plan wind tunnel tests of buildings.

86-1379
Seismic Analysis Methods for Irregular Buildings
J.P. Moehle, L.F. Alarcon
Univ. of California, Berkeley, CA
ASCE J. Struc. Engrg., 112 (1), pp 35-52 (Jan 1986) 13 figs, 1 table, 14 refs

KEY WORDS: Buildings, Reinforced concrete, Seismic analysis, Experimental data

A combined experimental and analytical study is made of the response to strong base motions of reinforced concrete structures having irregular vertical configurations. In the study, two frame-wall structures are constructed at small scale and subjected to earthquake simulations on a shaking table. Measured responses of the structures are compared with responses computed by several conventional analysis methods. The methods include inelastic dynamic response history analysis, inelastic static analysis, elastic modal spectral analysis, and elastic static analysis. Based on the data presented, it is concluded that the main advantage of the dynamic methods was that they were capable of estimating maximum displacement responses, whereas the static methods cannot be used for this purpose. In all other regards, the dynamic methods offered no clear advantage over the corresponding static method. The inelastic static and dynamic methods were superior to the elastic methods in interpreting effects of the structural discontinuities.

86-1380
Seismic Response Analysis of Nonlinear Structures Using the Stochastic Equivalent Linearization Technique
Tai-Ping Chang
Ph.D. Thesis, Columbia Univ., 96 pp (1985) DA8523129

KEY WORDS: Buildings, Seismic response, Equivalent linearization method, Stochastic processes

A solution method for the response of a class of nonlinear viscoelastic shear building structures subjected to stochastic excitation has been developed by means of a stochastic equivalent linearization technique. The nonlinear viscoelastic properties of the structures are modeled in terms of an equation of motion which linearly involves auxiliary variables as part of the restoring force and of the auxiliary equation which described a nonlinear relationship among the story displacements and auxiliary variables and their time derivatives. This auxiliary equation is linearized with the aid of a stochastic linearization technique which minimizes the expected value of the square of the difference between the nonlinear and linearized auxiliary equations. The variance function developed on the basis of the present analysis and those constructed by means of the Monte Carlo technique show a reasonable agreement.

86-1381
Simplified Methods of Analysis for Earthquake Resistant Design of Buildings
E. Cruz
Ph.D. Thesis, Univ. of California, Berkeley, CA, 255 pp (1985) DA8524919

KEY WORDS: Buildings, Seismic design, Response spectra, Spectrum analysis

This work on the development of simplified methods of analysis which are suitable for application to earthquake resistant design of buildings is organized in three parts. In Part I, the accuracy of the response spectrum analysis (RSA) for estimating the maximum response of a building directly from the earthquake design spectrum is evaluated. The objective is the development of preliminary design of buildings. In Part II, recognizing that the earthquake response of many buildings can be estimated by considering only the first two vibration modes in the response spectrum analysis (RSA) procedure, a simplified response spectrum analysis (SRSA) procedure is presented. In Part III, formulas for base shear, height-wise distribution of lateral forces, and computation of overturning moments specified in three design documents -- Uniform Building Code, Mexico's Federal District Building Code, and ATC-3 design provisions -- are evaluated.

86-1382
Linear and Nonlinear Analysis of Building Systems Subject to Multicomponent Earthquake Excitations
L.A. DeBejar
Ph.D. Thesis, Cornell Univ., 438 pp (1985) DA8517015

KEY WORDS: Buildings, Seismic excitation, Seismic analysis

This investigation develops a mathematical model for the 3-D earthquake analysis of building systems with rigid floors. A simple analytical model for the supporting elements leads to the natural extension of the conventional lateral-torsional elastic system of resistance into the analogous axial-rocking elastic system of resistance. It is shown that in the linear-elastic range both systems respond independently to the horizontal and vertical translational components of the ground motion, respectively.

86-1383
Structural Damage Assessment Using Response Measurements
J.E. Stephens
Ph.D. Thesis, Purdue, Univ., 253 pp (1985) DA8520078

KEY WORDS: Buildings, Seismic response

A technique is presented to assess seismic damage in existing structures using information readily obtainable from structural response records. Accelerograms are about the only type or response records currently available for real world structures following strong-motion earthquakes. Using the methodology as presented, these records are analyzed to estimate the force-deformation response at intervals along the height of the structure. The estimation scheme used in this study fits the response of a spring-mass model of the structure to the structural motions incrementally through time.

FOUNDATIONS

86-1384
Dynamic Response of a Partially Embedded Bar Under Transverse Excitations
R.Y.S. Pak
Ph.D. Thesis, California Inst. of Technology, 120 pp (1985) DA8519558

KEY WORDS: Bars, Pile structures, Underground structures, Flexural vibrations, Soil-structure interaction

This dissertation is concerned with the dynamic response of a finite flexible bar partially embedded in a half-space, under transverse loadings. The loadings are applied at the unembedded end of the bar and may, in general, be a combination of time-harmonic shear and moment. The problem is intended to serve as a fundamental idealization for the dynamic analysis of piles or other embedded foundations whose flexibilities are not negligible.

86-1385
Dynamic Analysis of Piles and Pile Groups Embedded in Non-Homogeneous Soils
R. Sen, E. Kausel, P.K. Banerjee
Univ. of South Florida, Tampa, FL
Intl. Numer. Anal. Methods Geomech., 2 (6), pp 507-524 (Nov/Dec 1985) 10 figs, 58 refs

KEY WORDS: Pile structures, Boundary element technique, Layered materials

A hybrid boundary element formulation for the steady state analysis of piles and pile groups embedded in a soil stratum in which the modulus increases linearly with depth is presented. The piles are represented by compressible columns of flexible beams and the soil is a hysteretic, layered medium. The explicit Green's function corresponding to dynamic loads in the interior of a layered stratum, developed earlier by Kausel is used in the study. The results of the analysis have been compared against those from alternative formulations, e.g. finite elements, and confirm the accuracy of the proposed formulation. Representative results for single piles and pile groups are presented.

86-1386
A Simplified Method for the Wave Equation Analysis of Pile Driving
S.A. Tan
Ph.D. Thesis, Univ. of California, Berkeley, CA, 270 pp (1985) DA8525134

KEY WORDS: Pile driving, Wave equation, Computer programs

The objective of this research was to develop a simplified method for the wave equation analysis of pile driving. Bearing graphs for a wide range of hammer and pile conditions, and for estimating the stresses in the pile during driving were developed. This research study has resulted in a method that can be applied to a wide variety of conditions, for cases of land-based piles driven with air/steam hammers. The method has the reliability and accuracy of the numerical wave equation method, but with sufficient simplicity to be accomplished quickly in the field with the aid of a programmable pocket calculator.

86-1387
Modeling of Recorded Three-Dimensional Earthquake Motion in the Frequency-Time Domain
M.F. Bendimerad
Ph.D. Thesis, Stanford Univ., 183 pp (1985) DA8522110

KEY WORDS: Ground motion, Seismic excitation, Mathematical models, Frequency domain method, Time domain method

In this study, three models of the recorded earthquake motion are developed on the basis of a nonstationary spectral analysis of the three recorded components. The first model corresponds to an axis transformation that diagonalizes the matrix of the moduli of the physical spectra and cross-physical spectra of the three instrument records. That transformation results in a single principal spectrum that for any frequency and at any time, is equal to the sum of the physical spectra of the original records. It is shown that the single accelerogram corresponding to the principal physical spectrum fully incorporates the time and frequency characteristics of the three recorded components. The two remaining models generate three mutually orthogonal ground motion accelerograms compatible with directions that optimize the instantaneous energies and the total energies of the recorded components, respectively. It is shown that the energy based accelerograms have time and frequency characteristics that are ordered on a well balanced scale of energy and intensity. In general, the use of those components results in a more reliable structural design.

86-1388
Random Vibration of Nonlinear Building Foundation Systems
Chien-Tsun Chu
Ph.D. Thesis, Univ. of Illinois at Urbana-Champaign, 181 pp (1985) DA8521745

KEY WORDS: Soil-structure interaction, Buildings, Foundations, Seismic excitation, Random vibrations

A method is presented for evaluating the effect of soil-structure interaction on the dynamic response of nonlinear building-foundation systems subjected to random seismic excitations. Uncertainties in the building-foundation system and loading are summarized and included in the

evaluation of the overall structural reliability. The subsystem approach is adopted to model a soil-structure system. The superstructure is modeled as a shear-beam; the substructure is considered as a surface foundation on a half-space. The nonlinear behavior in the coupled system is associated with the material nonlinearity in the structure and soil deposit, as well as the geometric nonlinearity caused by foundation uplifting. A smooth hysteretic model is used to represent the nonlinear behavior in the substructure as well as in the superstructure. For a structure with a large number of degrees of freedom, a DOF-reduction technique can be used to simplify the analysis. For structural reliability evaluation, the uncertainties in the dynamic modeling, the parameters of the coupled system, and the ground motion are also included. Using the available seismic hazard model, the lifetime safety of a building-foundation system can be evaluated.

HARBORS AND DAMS

86-1389
Earthquake Analysis and Response of Concrete Arch Dams
Ka-Lun Fok
Ph.D. Thesis, Univ. of California, Berkeley, CA, 202 pp (1985) DA8524950

KEY WORDS: Dams, Seismic analysis

Reliable analytical procedures to predict the earthquake response of arch dams are necessary to design earthquake resistant dams and to evaluate the earthquake safety of existing dams. The objectives of this investigation are to develop an effective and computationally efficient analytical procedure for computing the earthquake response of concrete arch dams, including the various effects of the impounded water, foundation rock, and alluvium and sediments invariably present at the boundary of reservoirs; and to study these effects on the response of arch dams to harmonic and arbitrary ground motion.

86-1390
Analysis of the Seismic Response of Prototype Earth and Rockfill Dams
Shyh-Shiun Lai
Ph.D. Thesis, Univ. of California, Berkeley, CA 286 pp (1985) DA8525023

KEY WORDS: Dams, Seismic response

A reliable determination of appropriate dynamic soil characteristics and an applicable analytical procedure are necessary in order to accurately assess the dynamic behavior of earth dams under cyclic loading conditions. Successful application of any analytical procedure for predicting the dynamic response of earth dams is essentially dependent on the incorporation of representative dynamic soil properties in the analyses.

86-1391
Contributions to Seismic Analysis of Earth Dams and Embankments
P.C. Dakoulas
Ph.D. Thesis, Rensselaer Polytechnic Inst., 227 pp (1985) DA8519488

KEY WORDS: Dams, Seismic analysis

An analytical closed-form solution is derived for the seismic analysis of embankment dams built in semi-cylindrical canyons, and the effects of canyon geometry on the dynamic response characteristics of the dam are investigated. Harmonic steady-state as well as transient accelerations, displacements and shear strains in the dam are studied. A general inhomogeneous shear beam model is developed for seismic analysis of earth dams and embankments. A simplified nonlinear numerical scheme is derived for estimating the response of dams to strong earthquake ground shaking.

OFF-SHORE STRUCTURES

86-1392
A Nonlinear Finite Element Method for the Analysis of the Offshore Pipelaying Problem
R.C. Malahy
Ph.D. Thesis, Rice Univ., 193 pp (1985) DA8517222

KEY WORDS: Offshore structures, Pipelines, Finite element technique

A finite element method is presented for the three dimensional, dynamic analysis of the offshore pipelaying problem. A geometrically nonlinear beam element and elastic bi-linear support elements are utilized to simultaneously model the pipeline, stinger, pipe supports and seabed. The results of numerical calculations are presented for a typical offshore pipelaying problem.

VEHICLE SYSTEMS

GROUND VEHICLES

86-1393
Dynamic Response of Ships in Random Waves
Y. Medury
Ph.D. Thesis, Univ. of Wisconsin - Madison, 134 pp (1985) DA8513470

KEY WORDS: Ships, Wave forces

The understanding of ship behavior in waves is assuming an important role in the design of high speed ships. The research presented is intended to develop an approach for calculating dynamic, wave-induced responses of moving, floating and flexible structures in random waves. The responses are obtained as the summation of the responses to deterministic surface waves of all frequencies, which models the random waves. The wave-induced loads are calculated using a non-linear strip theory; derived by a perturbational procedure.

MISSILES AND SPACECRAFT

86-1394
Control of Large Flexible Systems Via Eigenvalue Relocation
E.D. Denman, G.J. Jeon
Univ. of Houston, Houston, TX
Finite Elements Analy. Des., 1 (3), pp 241-253 (Nov 1985) 2 tables, 20 refs

KEY WORDS: Spacecraft, Vibration control, Eigenvalue problems

For the vibration control of large flexible systems, a control scheme by which the eigenvalues of the closed-loop systems are assigned to predetermined locations within the feasible region through velocity-only feedback is presented. Owing to the properties of second-order lambda matrices and an efficient model decoupling technique, the control scheme makes it possible that selected modes are damped with the rest of the modes unchanged.

MECHANICAL COMPONENTS

ABSORBERS AND ISOLATORS

86-1395
Behavior of Elastomeric Materials Under Dynamic Loads — IV
C.A. Caseiro
General Dynamics, Groton, CT
Shock Vib. Dig., 18 (1), pp 3-6 (Jan 1986) 34 refs

KEY WORDS: Elastomers, Sinusoidal excitation, Reviews

This is a review of literature published since 1982 on the behavior of rubber materials under sinusoidal forces. The most significant advances concern the correlation of dynamic properties and molecular structure.

BEARINGS

86-1396
Dynamic Analysis of Finite Half-Elliptical Pressure Dam Bearings with Rotor Flexibility Effects
N.P. Mehta, A. Singh, B.K. Gupta
Regional Engineering College, Kurukshetra, India
ASLE, Trans., 29 (1), pp 61-66, (Jan 1986) 8 figs, 30 refs

KEY WORDS: Bearings, Stiffness coefficients, Damping coefficients, Finite element technique

This paper presents an analytical study of dynamic characteristics of half-elliptical pressure dam bearings. One half (either upper or lower) of these bearings is elliptical, while the other half is circular. A step or pressure dam is cut in the upper half bearing surface. The lower half bearing surface is provided with a deep groove or relief-track. These bearings have been analyzed by the finite-element method. The results have been computed for dimensionless rotor flexibilities of 0.0, 0.5, 1.0, 2.0, and 4.0. Dynamic characteristics such as stiffness and damping coefficients, and stability threshold speed are presented in the form of graphs. It has been determined that half-elliptical pressure dam bearings are superior to circular pressure dam bearings in stability for bearings have same

design parameters. Both these half-elliptical pressure dam bearings have almost identical dynamic characteristics. Rotor flexibility adversely affects the stability of these bearings and its effect is pronounced at high Sommerfeld numbers.

86-1397
Design of Externally Pressurized Gas Bearings for Dynamic Applications
J.W. Roblee
Ph.D. Thesis, Univ. of California, Berkeley, 209 pp (1985) DA8525106

KEY WORDS: Gas bearings, Damping coefficients, Dynamic stiffness

This work accurately predicts the dynamic stiffness of gas bearings over a broad frequency range and shows that externally pressurized gas bearings can exhibit significant damping when properly designed. A new hybrid model of the dynamic stiffness of externally pressurized gas bearings is developed that incorporates the dominant distributed parameter characteristics of the bearing. This is accomplished by extending the analysis of squeeze films to include time-dependent-pressure boundary conditions and by linearly approximating the nonlinear frequency dependence of the flowrate and load solutions, including the geometry of the film.

86-1398
Measurements of Squeeze-film Bearing Forces and Pressures, Including the Effect of Fluid Inertia
J.A. Tichy
Rensselaer Polytechnic Institute, Troy, NY
ASLE, Trans., 28 (4), pp 520-526 (Oct 1985) 4 figs, 2 tables, 10 refs

KEY WORDS: Squeeze-film bearings, Squeeze-film dampers, Damping coefficients

Squeeze-film dampers are commonly applied to high-speed rotating machinery, such as aircraft engines, to reduce vibration problems. The Reynolds theory of hydrodynamic lubrication has been used for the design and modeling of dampers in rotor dynamic systems despite typical modified Reynolds numbers in applications between ten and fifty. Lubrication theory is strictly valid for Reynolds numbers much less than one, which means that fluid viscous forces are much greater than inertia forces. Theoretical papers which account for fluid inertia in squeeze films have predicted large discrepancies from lubrication theory, but these results have not found wide acceptance by workers in the field. Recently, experimental results on the behavior of rotor dynamic systems have been reported which strongly support the existence of large fluid inertia forces. In the present paper, direct measurements of damper forces and pressure are presented for the first time at high Reynolds number. Reynolds numbers up to 13 are obtained at eccentricity ratios 0.2, 0.5, and 0.8. Lubrication theory underpredicts the measured forces by up to a factor of two (100 percent error). Qualitative agreement is found with predictions of improved theories which include fluid inertia forces.

86-1399
Nonlinear Dynamics of Imperfect Fluid Journal Bearings
D. Wang
Ph.D. Thesis, Cornell Univ., 160 pp (1985) DA8525680

KEY WORDS: Journal bearings, Fluid-filled bearings, Geometric imperfection effects

A theoretical model for the study of effects of fluid journal bearing surface geometrical imperfection is developed. The imperfection on the journal and on the sleeve is considered separately. In each case, sinusoidal term and the model is described by a set of nonlinear ordinary differential equations. Analytical approach is adopted in this investigation to a great extent. The conditions involved in Reynolds equations are examined in the context of surface imperfections. Ocvirk short bearing approximation is used and the cavitation problem is dealt with Half-Sommerfeld boundary condition.

86-1400
Finite Element Analysis of Elastohydrodynamic Stern Tube Bearings
Z.P. Mourelatos
Ph.D. Thesis, Univ. of Mich, 231 pp (1985) DA8520951

KEY WORDS: Rotors, Bearings, Marine engines, Finite element technique, Oil film bearings

A finite element analysis is performed for a marine shafting/bearing system utilizing a hydrodynamic oil-lubricated stern tube bearing. The stern tube bearing analysis consists of three-dimensional finite element analysis of the shafting system, a two-dimensional finite element analysis of the oil film hydrodynamics, a three-dimensional finite element analysis of the bearing liner, and iterative techniques to establish the

equilibrium position among the shaft, the oil film, and the bearing material.

GEARS

86-1401
Investigation of the Influence of Gear System Parameters on Noise Generation
I. Nurhadi
Ph.D. Thesis, Univ. of Wisconsin-Madison, 224 pp (1985) DA8512321

KEY WORDS: Gears, Noise generation

This study deals with development of a procedure, based on a displacement based finite element method, for investigating noise generation, transmission and radiation from idealized gear systems. The systems under investigation are modeled as acoustic-structure interaction problems. The procedure incorporates an efficient time integration method suitable for calculating the dynamic time response. Examples include simulation of the interaction of a pair of gear teeth and investigation of the acoustic field inside and outside a gear box are presented.

86-1402
Inner Dynamic Forces at Teeth in High-Speed Planetary Gearings (Innere dynamische Zahnkräfte in hochtourigen Planetengetrieben)
G. Friedrich, R. Schulz
VEB Kombinat Getriebe und Kupplungen Magdeburg, Hauptabteilung Erzeugnisentwicklung Dresden
Maschinenbautechnik, 34 (10), pp 436-438 (1985) 3 figs, 2 tables, 3 refs (in German)

KEY WORDS: Planet gears, Gear teeth, Internal forces, Natural frequencies, Resonant response

By means of a program system of electronic data processing for automated computing oscillations natural vibrations as well as inner dynamic forces at teeth of a high-speed planetary gearing are computed. The results show, that not in each case wide amplitudes of vibration occur within resonance ranges authoritative for the inner dynamic forces at teeth. According to phase relation of excitation function acting at the periphery of central gears dangerous resonance vibrations are caused only in the one or the other resonance range.

FASTENERS

86-1403
Damping in Structural Joints
C.F. Beards
Imperial College of Science & Technology, London, UK
Shock Vib. Dig., 17 (11), pp 17-20 (Nov 1985) 33 refs

KEY WORDS: Joints, Structural damping

Joint damping is the major source of inherent structural damping. Because of increasing demands for higher damping, joints must be carefully controlled to yield the maximum damping compatible with the duty of the structure. To this end, refined analyses of damping and force transfer mechanisms in joints are being developed, and the range of application of joint damping is being increased.

86-1404
Analytical and Experimental Methodology for Evaluating Passively Damped Structural Joints
J.C. Prucz
Ph.D. Thesis, Georgia Inst. of Technology, 301 pp (1985) DA8519697

KEY WORDS: Joints, Viscoelastic damping

An innovative means to enhance the inherent damping in structures is provided by the designed-in incorporation of viscoelastic materials in joints. Passively damped joints are very attractive for large space structures due to their simplicity and high reliability. The joints, as envisioned, are double-lap shear joints that dissipate energy when worked in an axial direction. They may include a direct elastic connection between the members for improved minimum stiffness and structural redundancy at elevated temperatures or in the case of viscoelastic materials with poor creep resistance.

86-1405
Mode Coupling and Energy Partition of Sound in a System of Plate Junctions
B.M. Gibbs
University of Liverpool, Liverpool, England
J. Sound Vib., 104 (1), pp 127-136 (Jan 8, 1986) 9 figs, 15 refs

KEY WORDS: Joints, Plates, Sound waves, Wave generation

A description is given of a method of analysis of sound waves generated at a series of T-junctions of thin plates as a result of a wave incident on one of the plates. Mode coupling and energy partition are calculated for longitudinal, transverse shear and bending waves obliquely incident and it is seen that the transmission coefficient is strongly dependent on angle. Thus normal incidence characteristics are not a good indication of wave transmission in the configurations considered. The description is extended to include the effect of internal losses and the case is included where non-coupled edges parallel to the junctions are simply supported.

86-1406
Identification of Nonlinear Structural Elements by Force-State Mapping
E.F. Crawley, A.C. Aubert
Massachusetts Institute of Technology, Cambridge, MA
AIAA J., 24 (1), pp 155-162 (Jan 1986) 13 figs, 16 refs

KEY WORDS: Joints, Spacecraft, Force transmission, Force-state mapping technique

A major contributor to the passive damping and potentially nonlinear behavior of large space structures is the behavior of the joints. Proposed is an experimental technique called "force-state mapping" that will allow ground testing of these key structural elements. The technique includes the use of very accurate instrumentation to measure the force transmission properties of a structural element as a function of its mechanical state. When these data are presented in the form of a force-state map, the nonlinearities exhibit distinctively recognizable patterns. This presentation of the data allows the extraction of the describing parameters of the linear and nonlinear behavior and the energy dissipation characteristics of the joint. A series of tests were carried out on an idealized laboratory test article to demonstrate the technique. Strong structural nonlinearities, including a cubic hardening spring, friction and impact phenomena, were introduced and measured. Parameters identified by the force-state mapping technique are compared with those made by traditional techniques and the errors involved in the measurement are estimated.

SEALS

86-1407
An Analysis of "Ringing Phenomena" in a Water Pump Mechanical Seal (Part II)
K. Kiryu, T. Yanai, S. Matsumoto, T. Koga
Eagle Industry Co., Ltd., Okayama, Japan
ASLE, Trans., 29 (1), pp 25-34 (Jan 1986) 14 figs, 2 tables, 2 refs

KEY WORDS: Seals, Pumps, Stick-slip excitation

In a previous paper, the "ringing" phenomena in a water pump seal was experimentally analyzed. The conclusion was reached that the ringing sound was generated by the "stick-slip" phenomena attributed to both the lubrication characteristics of the sealing surfaces and also the vibration characteristics of the rotating shaft system. Subsequent to the previous investigation, a variety of vibration modes relevant to the stick-slip phenomena were confirmed. The present paper reports and discusses the vibration characteristics of the stick-slip movement by measuring torsional and bending strains of the rotating shaft system.

86-1408
Stability Threshold and Steady-State Response of Noncontacting Coned-Face Seals
I. Green, I. Etison
Technion, Haifa, Israel
ASLE, Trans., 28 (4), pp 449-460 (Oct 1985) 8 figs, 10 refs

KEY WORDS: Seals, Stability, Periodic response

The dynamic behavior of a noncontacting coned-face seal is analyzed. Stiffness and damping properties of the fluid film and flexible support including elastomeric secondary seal are fully accounted for. Stability threshold and steady-state response in the presence of rotor axial runout and assembly misalignment are investigated. An expressions is provided for the critical speed above which the seal becomes dynamically unstable. For stable operation, the relative misalignment between the mating faces is given as a function of rotor runout, assembly misalignment, design parameters, and operation conditions. An expression is provided for the critical rotor runout above which the seal will fail due to face contact. Although the analysis is based on small perturbation assumption, it is shown to be valid in many practical cases.

STRUCTURAL COMPONENTS

CABLES

86-1409
The Experimental Verification of a Towed Body and Cable Dynamic Response Theory
R.W. Bettles, D.A. Thomas

Univ. of Bath, Bath, UK
Ocean Engrg., 12 (5), pp 453-469 (1985) 11 figs, 3 refs

KEY WORDS: Cables, Towed bodies

Measurements of towed body motion in a laboratory towing tank have validated the mathematical model used as a basis for predicting body and cable dynamic behavior under seagoing conditions.

86-1410
Natural Frequencies and Modes of Hanging Nets or Curtains
W. Soedel, R.I. Zadoks, J.R. Alfred
Purdue Univ., West Lafayette, IN
J. Sound Vib., 103 (4), pp 499-507 (Dec 22, 1985) 4 figs, 2 tables, 6 refs

KEY WORDS: Cables, Wire cloth, Roofs, Natural frequencies, Mode shapes

Natural frequencies and modes are obtained for a rectangular hanging net or curtain whose horizontal fibers or cables are under uniform tension and whose vertical fibers or cables are acted on by a non-uniform tension produced by gravity. Mass and tension are averaged, thereby converting a net into an orthotropic membrane of equivalent mass and tension distribution. A closed form analytical solution of this approximate mathematical model is given. To verify the solution and to explore its limitation, the hanging net is also solved by a finite element schema, and the additional case of a net stretched uniformly over a rigid frame is treated.

86-1411
Natural Frequencies and Modes of Inclined Cables
M.S. Triantafyllou, L. Grinfogel
Massachusetts Inst. of Tech., Campbell, MA
ASCE J . Struc. Engrg., 112 (1), pp 139-148 (Jan 1986) 4 figs, 14 refs

KEY WORDS: Cables, Natural frequencies, Mode shapes, Asymptotic approximation

Asymptotic equations are derived for the natural frequencies and mode shapes of an elastic, taut, inclined cable. The equations are derived from more general asymptotic results by assuming quasi-static stretching. It is shown that for horizontal cables all previous results are recovered, while inclined cables have additional properties which cannot be obtained by using horizontal cable results. The phenomena of avoided crossings and hybrid mode formation are reviewed for inclined cables, in particular because of the significant dynamic tension amplification they induce.

BARS AND RODS

86-1412
Wave Attenuation in Periodic Structures
A.K. Roy, R. Plunkett
Univ. of Minnesota, Minneapolis, MN
J. Sound Vib., 104 (3), pp 395-410 (Feb 8, 1985) 12 figs, 15 refs

KEY WORDS: Beams, Periodic structures, Flexural waves, Wave attenuation

A periodic structure acts as a filter for traveling waves of any kind whether they be electromagnetic, acoustic, bending or anything else. This principle has been used to reduce the vibration level in one part of a structure when it is excited at another. For example, certain frequencies from engine excitation can be attenuated in the cabin of an aircraft. In this paper analytical methods for predicting the attenuation of bending waves is a dissipationless beam with flexible ribs attached to it are reported. The insertion loss (attenuation) spectra for a wide frequency range are then compared with measured results for test structures with 1 to 15 ribs attached. Some preliminary work was also done on the effect of rib spacing. The width of the attenuation band increased with increasing number of ribs with seven ribs giving almost as wide a band as it had for the infinitely long periodic beam. Since the structure has no dissipation, the attenuation is due solely to interference effects of multiple reflections.

86-1413
Low-Velocity Impact Response of Laminated Beams Subjected to Initial Stresses
B.V. Sankar, C.T. Sun
Bradley Univ., Peoria, IL
AIAA J ., 23 (12), pp 1962-1969 (Dec 1985) 15 figs, 2 tables, 16 refs

KEY WORDS: Beams, Layered materials, Impact response, Finite element technique

Finite element procedures are used in conjunction with a numerical algorithm to compute the impact response of a graphite-epoxy laminated beam subjected to tensile initial stresses. The

effects of initial stresses on the contact duration, impact force, coefficient of restitution, and bending and shear stresses are discussed. The analytically computed contact force history and strain response are compared with some experimental results.

86-1414
Non-Linear Vibratory Interactions in Systems of Coupled Beams
S.L. Bux, J.W. Roberts
Univ. of Edinburgh, Edinburgh, Scotland
J. Sound Vib., 104 (3), pp 497-520 (Feb 8, 1985) 10 figs, 26 refs

KEY WORDS: Beams, Coupled systems, Internal resonance, Autoparametric response, Nonsynchronous vibration

Small non-linear interactions of the type referred to as autoparametric may have a considerable effect on the forced oscillatory behavior of structures. Under conditions of internal resonance these effects may bring about complex forms of response where normal linear resonance of a directly excited mode is absorbed, and indirectly excited modes show simultaneous large non-synchronous responses. In this paper the forces vibration of a system of coupled beams is examined and it is shown that violent non-synchronous torsion and bending vibration observed in such a system may be explained by the existence of quadratic nonlinear coupling terms and internal resonance effects between three and four modes.

86-1415
Discussion of Finite Element Formulations of Nonlinear Beam Vibrations
Chuh Mei
Old Dominion Univ., Norfolk, VA
Computers Struc., 22 (1), pp 83-85 (1986) 1 table, 17 refs

KEY WORDS: Beams, Finite element technique

The Lagrange-type, Galerkin, and Ritz-type finite element formulations for large amplitude vibrations of immovably supported slender beams are reexamined. Inconsistency in the definition of frequency or criterion of defining nonlinearity is discussed, and validity of the frequency solution is examined. Improved finite element results by including both longitudinal displacement and inertia in the formulation are presented and compared with available Rayleigh-Ritz continuum solutions.

86-1416
Vibration of Damped Plate-Oscillator Systems
J.W. Nicholson, L.A. Bergman
Shell Development Co., Houston, TX
ASCE J. Engrg. Mech., 112 (1), pp 14-30 (Jan 1986) 9 figs, 1 table, 32 refs

KEY WORDS: Beams, Plates, Natural frequencies, Mode shapes, Viscous damping

A classical method for obtaining the exact natural frequencies, natural modes, orthogonality relation and response due to arbitrary loading of undamped beam-oscillator systems. The natural modes are expressed in terms of the Green's function for the vibrating plate. Damping is present in both the plate and oscillators. Modal analysis allows the determination of a closed form expression for the system response to arbitrary loading. Oscillators attached to a simply supported rectangular plate have been considered, but the method is applicable to any plate-oscillatory system, provided the Green's function for the undamped vibrating plate is known. An example involving a single oscillator attached to the plate shows the natural frequencies, natural modes and response due to two special types of loading.

86-1417
Natural Vibration and Buckling of General Periodic Lattice Structures
M.S. Anderson, F.W. Williams
NASA Langley Research Center, Hampton, VA
AIAA J., 24 (1), pp 163-169 (Jan 1986) 8 figs, 1 table, 10 refs

KEY WORDS: Grids (beams), Natural frequencies

A method is presented for vibration and buckling analysis of arbitrary lattice structures having repetitive geometry in any combination of coordinate directions. The approach is based on exact member theory representing the stiffness of an individual member subject to axial load and, in the case of the vibration, undergoing harmonic oscillation. The method is an extension of previous work that was limited to specific geometries. The resulting eigenvalue problem is of the size associated with the repeating element of the structure. A computer program has been developed incorporating the theory, and results are given for vibration of rectangular platforms and a large antenna structure having rotational symmetry. Buckling and vibration results for cable-stiffened rings are also given.

86-1418
Modeling Global Structural Damping in Trusses Using Simple Continuum Models
C.T. Sun, J.N. Juang
Purdue Univ., West Lafayette, IN
AIAA J., 24 (1), pp 144-150 (Jan 1986) 6 figs, 3 tables, 7 refs

KEY WORDS: Beams, Trusses, Timoshenko theory, Viscous damping

Truss beams with members having viscous damping are modeled as continuum Timoshenko beams. Procedures for deriving the equivalent beam stiffnesses and damping are presented. The global damping for the continuum beam is explicitly expressed in terms of the damping coefficients of the individual truss members. The continuum beam model is used to study transient vibration problems and the solutions compare well with the full-scale finite element solutions. The gradient method is used for parameter estimations in conjunction with the Timoshenko beam model. It is shown that the Timoshenko beam model can be updated easily with measured data and that the updated model can yield very accurate transient solutions.

86-1419
A New Method of Analyzing Wave Propagation in Periodic Structures; Applications to Periodic Timoshenko Beams and Stiffened Plates
D.J. Mead
Univ. of Southampton, Southampton, England
J. Sound Vib., 104 (1), pp 9-27 (Jan 8, 1986) 7 figs, 13 refs

KEY WORDS: Beams, Plates, Timoshenko theories, Periodic structures, Wave propagation

A response function is found for an infinite, uniform, one-dimensional structure which is subjected to an array of harmonic forces or moments, spaced equidistantly, and which have a constant phase or ratio between any adjacent pair. Receptance functions are derived for these "phased arrays". They are used to set up a general determinantal equation for the propagation constants of the infinite structure when it is made periodic by the addition of an infinite set of regular constraints. They are also used to set up equations for the response of the structure to a convected harmonic pressure field. The method enables the equations for the propagation constants and for the response to convected loading to be set up with much greater facility than by earlier methods. It only required a knowledge of the response function of the infinite uninterrupted structure under a single-point harmonic force or moment.

86-1420
Frequency-dependent Matrices for Tapered Beams
A.K. Gupta
Quadrex Corp., Campbell, CA
ASCE J. Struc. Engrg., 112 (1), pp 85-103 (Jan 1986) 5 figs, 2 tables, 6 refs

KEY WORDS: Beams, Variable cross section, Stiffness matrices, Mass matrices

Dynamic correction stiffness and mass matrices are derived in explicit form for a tapered beam element of any cross-sectional shape. These matrices are derived using exact expressions for the required displacement functions. Variation of area and moment or inertia of cross section along the axis of the element is exactly represented by simple functions involving shape factors. Vibration analysis of an example tapered beam is performed using static and dynamic correction tapered beam element matrices, and uniform beam element matrices. The costs, and advantages and disadvantages of analyzing tapered beams using these matrices are considered.

CYLINDERS

86-1421
Response of and Sound Radiation from a Layered Cylinder with Regular Axial Stiffeners
E.S. Reddy, A.K. Mallik
Arizona State Univ., Tempe, AZ
J. Sound Vib., 103 (4), pp 519-531 (Dec 22, 1985) 6 figs, 1 table, 14 refs

KEY WORDS: Cylinders, Layered materials, Stiffeners, Sound waves, Wave radiation

Response and sound radiation characteristics of a three-layered cylinder with equispaced (periodic) axial stiffeners are obtained using the "wave" approach. A two-dimensional situation with no variation of the axial direction is considered. Numerical results are presented for the case of three stiffeners, which are assumed to prevent both radial and tangential displacements of the base layer. The pressure harmonics exciting various modes are analyzed. Three different types of interior, namely, totally resonant or absorbent and partially absorbent, are investigated and their effects on the response and sound power radiation are studied.

86-1422
On the Calculation of Two-Dimensional Added Mass and Damping Coefficients by Simple Green's Function Technique
P. Andersen, H. Wuzhou
Technical Univ. of Denmark, Lyngby, Denmark
Ocean Engrg., 12 (5), pp 425-451 (1985) 3 figs, 2 tables, 10 refs

KEY WORDS: Cylinders, Underwater structures, Mass coefficients, Damping coefficients, Green function

This paper describes a numerical method for calculating the two-dimensional hydrodynamic coefficients of one or two infinitely long, arbitrary cylinders forced to oscillate in or below the free water surface. The oscillation modes, amplitudes and phases of the cylinders may be different from one another. Finite water depth and a quay can be taken into account. Special consideration has been given to the radiation boundary conditions. The computer program developed has been tested in various two-dimensional boundary situations; it has produced results in good agreement with results obtained by other methods.

FRAMES AND ARCHES

86-1423
Micro-Computer Based Dynamic Analysis of Linear Undamped Plane Frame Structures
L. Goshorn
Texas A & M Univ., College Station, TX
71 pp (Aug 1985) AD-A152 902/7/GAR

KEY WORDS: Framed structures, Finite element technique, Mode shapes, Computer programs, Microcomputers

This paper presents an assimilation of mathematical models and solutions needed in order to develop computer based analysis of dynamic structures. Using the variational formulation and a direct integration technique, a dynamic finite element model is developed. Modal analysis of unknown displacement of the structure, and the dynamic reduction of the structure are presented as alternative solutions. A system of micro-computer based programs which apply the presented solution techniques is described. The system of programs support varying cross sections of frame members, application of static, harmonic and non-harmonic loading conditions, and node displacement in the form of uniform base motion or independent node movement.

MEMBRANES, FILMS, AND WEBS

86-1424
Exact Vibration Solutions for Some Irregularly Shaped Membranes and Simply Supported Plates
H.P.W. Gottlieb
Griffith Univ., Nathan, Queensland, Australia
J. Sound Vib., 103 (3), pp 333-339 (Dec 8, 1985) 2 figs, 41 refs

KEY WORDS: Membranes, Plates, Natural frequencies, Mode shapes, Fundamental modes

A procedure is discussed for realizing some exact analytical eigenfunctions and corresponding eigenfrequencies for vibrating membranes with fixed rectilinear edges delineable on a grid of squares and their diagonals. By the membrane-plate analogy, the corresponding eigenmodes and frequencies of simply supported vibrating plates of the same shapes may be obtained. The fundamental modes of certain shapes with curved boundaries are also considered.

PLATES

86-1425
***Vibration of* Thick Plates Carrying Concentrated Masses**
J.W. Nicholson, L.A. Bergman
Univ. of Illinois at Urbana-Champaign, Urbana, IL
J. Sound Vib., 103 (3), pp 357-369 (Dec 8, 1985) 1 table, 51 refs

KEY WORDS: Plates, Transverse shear deformation effects, Rotatory inertia effects, Natural frequencies, Green function

The method for obtaining the natural frequencies and orthogonality relation for combined dynamical systems in which the Green functions of the vibrating subsystems are used is applied to a thick plate carrying concentrated masses. The effects of transverse shear and rotary inertia of each mass is accounted for. It is demonstrated that as the plate thickness goes to zero the results of thin plate analysis are obtained. The Green functions for both thin and thick vibrating plates are derived by modal analysis in the form of infinite series. The advantages and disadvantages of this representation are discussed. An example involving a simply supported isotropic square plate carrying a single concentrated mass at its center is provided.

86-1426
Vibration of Plates with Straight-line, Clamped and Free Edges
K. Poltorak
Warsaw Technical Univ., Warsaw, Poland
J. Sound Vib., 104 (3), pp 437-447 (Feb 8, 1985) 9 figs, 1 table, 12 refs

KEY WORDS: Plates, Flexural vibration, Boundary value problems, R-function method

This paper deals with vibration problems of thin plates having straight-line, mutually perpendicular, clamped and free edges and subjected to a load consisting of a set of transverse, arbitrarily located random forces. It is assumed that the number of edges of a plate forming recurring figures is optional but each of these edges is either clamped or free along its entire length. The procedure for solving the boundary problem based upon the R-functions method and for estimation of transverse displacements based upon the correlation analysis is presented. Numerical calculations are carried out for two example plates.

86-1427
Vibrations of Plates of Arbitrary Shape by a Modified Galerkin Method
L. Ercoli, L.C. Nava, P.A.A. Laura
Institute of Applied Mechanics, Puerto Belgrano Naval Base, Argentina
J. Sound Vib., 103 (4), pp 545-548 (Dec 22, 1985) 2 figs, 1 table, 5 refs

KEY WORDS: Plates, Fundamental frequencies, Galerkin method, Conformal mapping

This paper deals with a modification of Galerkin's method which allows for the optimization of the fundamental eigenvalue when a single coordinate function is used. Use of the conformal mapping method allows for the consideration of two dimensional domains of complicated boundary shape.

86-1428
Stability and Natural Vibration Analysis of Laminated Plates by Using a Mixed Element Based on a Refined Plate Theory
N.S. Putcha, J.N. Reddy
Virginia Polytechnic Institute and State Univ., Blacksburg, VA
J. Sound Vib., 104 (2), pp 285-300 (Jan 22, 1986) 12 figs, 6 tables, 20 refs

KEY WORDS: Plates, Layered materials, Natural frequencies, Mixed element technique, Finite element technique

A mixed shear flexible finite element, with relaxed continuity, is developed for the geometrically linear and nonlinear analysis of layered anisotropic plates. The element formulation is based on a refined higher order theory which satisfies the zero transverse shear stress boundary conditions on the top and bottom faces of the plate and requires no shear correction coefficients. The mixed finite element developed consists of eleven degrees of freedom per node which include three displacements, two rotations, and six moment resultants. The element is evaluated for its accuracy in the analysis of the stability and vibration of anisotropic rectangular plates with different lamination schemes and boundary conditions. The mixed finite element described here for the higher order theory gives very accurate results for buckling loads and natural frequencies.

86-1429
Vibration and Damping Analysis of Fibre Reinforced Composite Material Plates
N. Alam, N.T. Asnani
I.I.T., Delhi, India
J. Composite Materials, 20 (1), pp 2-18 (Jan 1986) 4 figs, 7 tables, 15 refs

KEY WORDS: Plates, Fiber composites, Layered materials, Vibration response, Damping coefficients

Governing equations of motion for a laminated plate consisting of an arbitrary number of fiber reinforced composite material layers have been derived using the variational principles. Each layer has been considered to be of a specially orthotropic material with its directional elastic properties depending on the fiber orientation. Extension, bending, inplane shear and transverse shear deformations in each layer are considered. The longitudinal translatory and the rotary inertias along with the transverse inertia are taken into account. A solution for simply supported rectangular plate is obtained in series summation form and the damping analysis is carried out by an application of the correspondence principle of linear viscoelasticity. The computer program for the determination of the resonating frequencies and the associated system loss factors for the various families of modes of vibration of a plate consisting of an arbitrary number of layers has been developed. Using the same, investigation for the optimum fiber orientation for maximizing the resonant frequencies and the system loss factors for the flexural and the extensional modes of vibration of a four layered criss-cross laminated plate, has been carried out. The variation of the

resonant frequencies and the system loss factors with aspect ratio, for the first flexural modes of 2, 4, and 6 layered cross-ply laminated plates are also reported.

86-1430
Vibration and Buckling of Laminated Composite Plates with Arbitrary Boundary Conditions
B. Baharlou
Ph.D. Thesis, Ohio State Univ., 151 pp (1985)
DA8518914

KEY WORDS: Plates, Layered materials, Composite structures, Boundary condition effects, Natural frequencies

Laminated composite plates are presently widely used because of their many significant advantages and the problems of vibration and buckling of these structural elements has attracted the attention of many researchers over the last two decades. In this study an accurate and economical analytical approach is developed to find natural frequencies and buckling loads for all the possible combinations of the geometric boundary conditions that exist for a rectangular laminated composite plate. The Ritz method is used with ordinary algebraic polynomials as displacement functions.

86-1431
Transverse Vibrations of Hybrid Laminated Plates
N.G.R. Iyengar, J.R. Umaretiya
Indian Institute of Technology, Kanpur, India
J. Sound Vib., 104 (3), PP 425-435 (Feb 8, 1985)
8 figs, 1 table, 9 refs

KEY WORDS: Plates, Layered materials, Galerkin method, Flexural vibrations

In this paper, an attempt is made to obtain the free vibration response of hybrid, laminated rectangular and skew plates. The Galerkin technique is employed to obtain an approximate solution of the governing differential equations. It is found that this technique is well suited for the study of such problems. Results are presented in a graphical form for plates with one pair of opposite edges simply supported and the other two edges clamped. The method is quite general and can be applied to any other boundary conditions.

86-1432
A Finite Element Analysis of the Harmonic Response of Damped Five-Layer Plates
E. Ioannides, P. Grootenhuis
SKF European Research Centre, Nieuwegein, The Netherlands
IMechE, Proc., Part C: Mech. Engrg. Sci., 199 (C4), pp 311-317 (1985) 6 figs, 1 table, 14 refs

KEY WORDS: Plates, Layered materials, Damped structures, Harmonic response, Finite element technique

Solutions have been obtained for the harmonic vibrations of five-layer plates by means of a finite element method. This method is an extension of a previously developed analysis for three-layer plates. The five-layer plates contain two constrained viscoelastic layers which provide the damping. The degenerate case when the thickness of the middle elastic layer becomes zero and the plate is reduced to a four-layer one has also been included in the solution procedure. Moreover, the method allows for the study of both torsional and transverse vibrations of five (or four)-layer beams treated as vibrating plates with a large aspect ratio. As in the case of three-layer plates, triangular finite elements are used to allow for a greater variety of shapes. In the analysis damping is introduced by replacing the real moduli of the viscoelastic material by complex equivalent moduli which account for the phase difference between strain and stress. The present method allows for nonlinear stress-strain behavior of the viscoelastic layers, the effects of the rotatory inertia and the extension within the viscoelastic layers. The finite element computations have been verified by comparison with experimental results for four-layer and five-layer beams in transverse and torsional vibrations and a five-layer square plate in transverse vibrations.

86-1433
A Note on the Determination of the Fundamental Frequency of Vibration of a Rectangular Plate with a Free, Semicircular Cut-Out Along the Edge
P.A.A. Laura, L. Ercoli, J. Baron, G. Sanchez Sarmiento
Institute of Applied Mechanics, Puerto Belgrano Naval Base, Argentina
J. Sound Vib., 104 (1), pp 1-8 (Jan 9, 1986) 6 figs, 2 tables, 6 refs

KEY WORDS: Rectangular plates, Discontinuity-containing media, Fundamental frequencies, Ritz method

The title problem is tackled by using polynomial coordinate functions and the Ritz method in order to generate an approximate frequency equation. It is shown that in the case of a

clamped square plate the results are in good engineering agreement with frequency values obtained by means of the finite element method when the cut-out size is small relative to the plate dimensions. Experimental results are also presented and it is shown that they are in excellent agreement with finite element values.

86-1434
Dynamical Study of Flat Plates by Nonlinear Elasticity Theory (Sullo Studio Dinamico Dei Pannelli Piani Conla Teoria Elastica Non Lineare)
G. Surace
Politecnico de Torino, Italy
Rept. No STN-8, 13 pp (Oct 1984) N85-31572/9/GAR (in Italian)

KEY WORDS: Rectangular plates, Nonlinear theories, Equivalent linearization method

Nonlinear theory is used to solve the problem of the transient period and of the dynamic response of a flat rectangular plate with simply supported edges, subjected to a periodic forcing action. Equivalent linearization techniques are used. The influence of nonlinear analysis on the computed dynamic characteristics is shown.

86-1435
Acoustic Scattering by a Soft Elliptic Disk
G. Kristensson
Institute of Theoretical Physics, Göteborg, Sweden
J. Sound Vib., 103 (4), pp 487-498 (Dec 22, 1985) 9 figs, 9 refs

KEY WORDS: Disks, Sound waves, Wave scattering

Scattering from an acoustically soft elliptic disk is treated by means of the null field approach. It is shown that in the disk limit of a general ellipsoid the relevant matrix elements have a well-defined limit, and that the formulation is attractive for numerical calculations. In a separate section the low frequency expressions of the total cross section and the far field amplitude are also derived. The paper is closed by a presentation of a series of numerical calculations.

86-1436
Buckling and Vibrations of Polar Orthotropic Annular Plates of Variable Thickness
U.S. Gupta, R. Lal, C.P. Verma
Univ. of Roorkee, Roorkee, India
J. Sound Vib., 104 (3), pp 357-369 (Feb 8, 1986) 4 figs, 4 tables, 12 refs

KEY WORDS: Annular plates, Variable cross section, Axisymmetric vibration

The effect of an hydrostatic in-plane force, together with the orthotropy, on the axisymmetric vibrations of an annular plate of linearly varying thickness in the radial direction has been analyzed on the basis of classical theory of plates. The numerical solution of the governing differential equation for two boundary conditions (inner and outer both clamped; inner clamped and outer simply supported at the periphery) has been obtained by a spline technique. Transverse displacements, moments in normalized form for a particular set of plate parameters and buckling loads in compression with thickness variation and various values of rigidity ratios have been computed for first two modes of vibrations. A comparison of present results with those available in the literature shows a very good agreement.

86-1437
Large Amplitude Vibrations of Clamped Circular Plates of Linearly Varying Thickness
S.K. Ghosh
Hooghly Mahsin College, Hooghly, West Bengal, India
J. Sound Vib., 104 (3), pp 371-375 (Feb 8, 1986) 3 tables, 7 refs

KEY WORDS: Circular plates, Variable cross section, *Vibration response*

The large amplitude vibrations of clamped circular plates of linearly varying thickness are investigated.

SHELLS

86-1438
Deterministic and Non-Deterministic Response Analysis of Complex Shells
R.K. Kapania
Ph.D. Thesis, Purdue Univ., 187 pp (1985) DA 8520023

KEY WORDS: Shells, Finite element technique, Cooling towers, Seismic response, Wind-induced excitation

Finite element analysis capabilities are developed for performing deterministic and nondeterministic responses of complex thin shells. A set of shell elements is adopted, modified or extended to study the seismic and wind responses of col-

umn-supported cooling towers. The elements are formulated intending to achieve optimum finite element modeling of the column-supported cooling towers according to the distributions of dominating bending and membrane stresses, and intending to model the vulnerable shell-column region using discrete column elements and quadrilateral shell elements.

86-1439

On the Analysis of Shell Structures Subjected to a Blast Environment: A Finite Element Approach

G.R. Heppler
Ph.D. Thesis, Univ. of Toronto, Canada (1985)

KEY WORDS: Shells, Blast response, Finite element technique, Nuclear explosion effects

The development of a finite element technique designed specifically for the analysis of blast loaded (chemical explosions) or combined blast and thermally loaded (nuclear explosions) circular cylinders is outlined. Following a brief introduction the formulation of the stiffness matrix is presented which includes discussions of the material and geometric nonlinearities included in the finite element model. The consistent force vector calculation is illustrated in the next chapter including techniques used to deal with thermal loading and blast wave loading. Subsequently examples and results are presented which verify the accuracy and versatility of the static formulation of the problem. To lead into the dynamic analysis the consistent mass matrix development is presented along with that for a companion diagonal mass matrix which exhibits dynamically correct behavior. The requirements of temporal integration schemes are investigated and the necessary and sufficient conditions for a linear single step integration method to be stable when operating on a system of motion equations in which the damping matrix is nonproportional are presented. Finally, examples of dynamic analyses, including a cylinder loaded by a nuclear burst, using the methods outlined are presented.

86-1440

Method to Determine Dynamic Elastic Constants of Thin Shell Composites by Guided Ultrasonic Waves

J.V. Foltz, A.L. Bertram, C.W. Anderson
Naval Surface Weapons Ctr., Silver Spring, MD
Rept. No. NSWC/TR-85-186, 32 pp (June 15, 1985) AD-A159 025/6/GAR

KEY WORDS: Shells, Composite structures, Dynamic properties, Ultrasonic techniques

Ultrasonic techniques are used to determine the velocities of guided waves in unidirectional metal matrix composite places. Both extensional (fundamental Lamb symmetric) and in-plane shear (SH) plate wave speeds are measured via through-transmission procedures utilizing one-half megahertz broadband transducers. The values recorded for the wave speeds and the plate density are used to calculate the four reduced stiffness coefficients of the plane stress Hooke's Law relationship of the plate. This approach allows the full set of elastic constants required by designers for the analysis of a thin orthotropic plate or shell loaded in its plane to be obtained from only four ultrasonic measurements. The accuracy of the elastic constant determinations may be increased by measuring more than four wave speeds and employing the statistical data reduction method described.

86-1441

Forced Oscillations of an Axisymmetric Structure in Contact with an Elastic Half-Space by a Version of Global Local Finite Elements

V. Avanessian, R. Muki, S.B. Dong
Univ. of California, Los Angeles, CA
J. Sound Vib., 104 (3), pp 449-463 (Feb 8, 1985)
6 figs, 1 table, 18 refs

KEY WORDS: Bodies of revolution, Periodic response, Finite element technique

A version of the global local finite element method (GLFEM) is presented for determining the steady state forced response of an axisymmetric structure in contact with an elastic, homogeneous, isotropic half-space. In this GLFEM version, conventional finite elements are used to model the structure and some portion of the surrounding medium, and global functions in the form of a composite set of outgoing spherical harmonic waves for the entire space are used to capture the behavior of the half-space region beyond the finite element mesh. An arbitrary distribution of steady state normal loads may be applied to the structure. Full traction and displacement continuity are enforced at the finite element mesh interface with the outer region. On the half-space surface of the outer region, traction-free surface conditions are met by requiring a sequence of weighted-average integrals of the tractions to vanish.

86-1442

Free Vibration of a Point-supported Spherical Shell

T. Irie, G. Yamada, Y. Muramoto
Hokkaido Univ., Sapporo, Japan

J. Appl. Mech., 52 (4), pp 890-896 (Dec 1985) 5 figs, 3 tables, 15 refs

KEY WORDS: Spherical shells, Natural frequencies, Mode shapes, Supports

An analysis is presented for the free vibration of an elastically or a rigidly point-supported spherical shell. For this purpose, the deflection displacements of the shell are written in a series of the products of the associated Lengendre functions and the trigonometric functions. The dynamical energies of the shell are evaluated, and the frequency equation is derived by the Ritz method. For a rigidly point-supported shell, the Lagrangian multiplier method is conveniently employed. The method is applied to a closed spherical shell supported at equispaced four points located along a parallel of latitude; the natural frequencies and the mode shapes are calculated numerically, and the effects of the point supports on the vibration are studied.

86-1443
Dynamic Stability of Liquid-Filled Cylindrical Shells Under Horizontal Excitation, Part I: Experiment
M. Chiba, J. Tani, H. Hashimoto, S. Sudo
Iwate Univ., Morioka, Japan
J. Sound Vib., 104 (2), pp 301-319 (Jan 22, 1986) 18 figs, 9 refs

KEY WORDS: Cylindrical shells, Fluid-filled containers, Cantilever shells, Harmonic excitation, Dynamic stability

Experimental studies have been carried out on the dynamic stability of a cantilever cylindrical shell partially filled with liquid, under horizontal excitation. The test cylinder was harmonically excited with constant acceleration or displacement amplitude. It was found that a combination instability resonance of sum type could occur, involving two natural vibrations with the same axial mode of vibration number but with the circumferential wave numbers differing by one. By varying the dimensionless water height from 0 to 1·0 stepwise by 0·25 increments, the instability regions and vibration modes were determined for two polyester test cylinders. The response waves, axial and circumferential vibration modes, and behavior of the free liquid surface were also observed.

86-1444
Vibration of a Cracked Cylindrical Shell of Rectangular Planform
R. Solecki, F. Forouhar
Univ. of Connecticut, Storrs, CT
J. Appl. Mech., 52 (4), pp 927-932 (Dec 1985) 4 figs, 2 tables, 22 refs

KEY WORDS: Cylindrical shells, Cracked media, Harmonic response

Harmonic vibrations of a circular, cylindrical shell of rectangular planform and with an arbitrarily located crack, are investigated. The problem is described by Donnell's equations and solved using triple finite Fourier transformation of discontinuous functions. The unkowns of the problem are the discontinuities of the slope and of three displacement components across the crack. These last quantities are replaced, using constitutive equations, by curvatures and strain in order to improve convergence and to represent explicitly the singularities at the tips. The formulas for differentiation of discontinuous functions are derived using Green-Gauss theorem. Application of the boundary conditions at the crack leads to a homogeneous system of linear algebraic equations. The frequencies are obtained from the characteristic equation resulting from this system. Numerical results for special cases are provided.

RINGS

86-1445
Vibration of Shear Deformable Rings: Theory and Experiment
T.G. Gardner, C.W. Bert
Kerr-McGee Coal Corp., Oklahoma City, OK
J. Sound Vib., 103 (4), pp 549-565 (Dec 22, 1985) 6 figs, 4 tables, 16 refs

KEY WORDS: Rings, Curved beams, Natural frequencies, Mode shapes

A new first-approximation theory is presented for analysis of the inplane dynamic behavior of shear deformable ring structures. This theory may be applied to curved beams as well as complete rings. Natural frequencies and associated vibrational modes for a complete ring are investigated experimentally using modern instrumentation and experimental techniques. The natural frequencies predicted by the new theory are compared with the new experimental data as well as some previously reported data and predictions from thin-ring theory, various other shear deformable theories, elasticity theory, and various finite element analyses. The present theory includes a description of transverse shear

strain which permits satisfaction of the physical requirements of zero shear stress at the inner- and outer-ring surfaces. Transverse shear strain is an important effect when analyzing thick, homogeneous, material rings and even more significant for rings made of composite materials. This theory is an advancement over Bresse-type, shear-correction theories, which utilize a shear correction factor determined in an ad hoc fashion.

86-1446
On the In-Plane Vibrations of a Rotating Ring with Equi-Spaced Spokes
E.S. Reddy, W.B. Bickford
Arizona State Univ., Tempe, AZ
J. Sound Vib., 103 (4), pp 533-544 (Dec 22, 1985) 7 figs, 11 refs

KEY WORDS: Rings, Rotating structures, Spokes, Natural frequencies

Natural frequencies are obtained for a rotating ring with equi-spaced spokes by using a wave approach. Each spoke is idealized as a combination of tangential, rotational, and radial stiffnesses acting at the mid-plane of the ring. Results show the effect of rotational speed and spoke stiffness on the natural frequencies. The presence of a zero natural frequency at certain rotational speeds and also at certain spoke stiffnesses is discussed.

PIPES AND TUBES

86-1447
Three-Dimensional Dynamic Response of Buried Pipelines to Incident Longitudinal and Shear Waves
S.K. Datta, P.M. O'Leary, A.H. Shah
Univ. of Colorado
J. Appl. Mech., 52 (4), pp 919-926 (Dec 1985) 14 figs, 15 refs

KEY WORDS: Pipelines, Underground structures, Shells, Longitudinal waves, Shear waves

An exact analysis is presented here for the three-dimensional dynamics of a long continuous pipeline embedded in an elastic medium. A shell model of the pipe has been used here. It is shown that the dynamic amplification of axial and hoop stresses induced in the pipe due to incident plane longitudinal and shear waves depends crucially on the ratio of rigidities of the surrounding soil and the pipe. Induced stresses are also found to have appreciable frequency dependence for certain combinations of material properties and angles of incidence. Results presented here are also applicable to buried tunnels.

DUCTS

86-1448
A Finite Difference Scheme for Acoustic Transmission Through the Walls of Distorted Circular Ducts and Comparison with Experiment
A. Cummings, I.-J. Chang
Univ. of Missouri-Rolla, Rolla, MO
J. Sound Vib., 104 (3), pp 377-393 (Feb 8, 1986) 7 figs, 10 refs

KEY WORDS: Ducts, Sound waves, Wave propagation, Finite difference technique

A numerical method is developed to find the structural response of the walls of cylindrical distorted circular ducts to internal plane acoustic travelling waves, and hence the internal/external sound transmission loss. Comparisons are made between experiment and theory for two "long seam" air conditioning ducts and a squashed spiral-wound air conditioning duct. In general, reasonable agreement is obtained, when the accuracy of the geometrical specification of the ducts is taken into account. The generality of the computing code allows the method to be applied to cylindrical ducts of virtually any geometry where the radius of curvature and its first and second derivatives can be considered continuous around the duct perimeter. It is concluded that "mode-coupling" effects appear to offer a plausible explanation for the effect of wall distortion in lowering the duct wall transmission loss.

86-1449
The Propagation of Sound in a Square Duct with a Non-Rigid Side Wall
A. Cabelli
Commonwealth Scientific and Industrial Research Organization, Melbourne, Australia
J. Sound Vib., 103 (3), pp 379-394 (Dec 8, 1985) 12 figs, 16 refs

KEY WORDS: Ducts, Sound waves, Wave propagation

The propagation of sound in ducts is examined for the case of a side wall excited by acoustic waves inside the duct. The equations which describe the coupling between acoustic waves and structural vibrations are solved and salient features of the interaction are illustrated. The simultaneous propagation of a number of acoustic contributions is found necessary to describe the coupling near resonance and at high frequencies. At low frequencies one acoustic mode may be sufficient. Two sets of material properties are used to illustrate that coincidence cannot always be predicted from isolated acoustic and structural considerations.

86-1450
Non-Linear Effect of Wall Linings on Sound Attenuation in Ducts
M. Namba, K. Kobayashi
Kyushu Univ., Fukuoka, Japan
J. Sound Vib., 103 (3), pp 395-415 (Dec 8, 1985)
19 figs, 8 refs

KEY WORDS: Ducts, Linings, Acoustic absorption

The equivalent surface source method is extended to the analysis of high intensity sound propagation in a duct whose wall is partially treated with a sound absorbing material. The propagation of sound in the gas is assumed to be linear, but the acoustic resistance of the sound absorbing material is assumed to be a function of the normal acoustic velocity. The problem is reduced to a non-linear integro-differential equation for the fluid particle displacement at the lined wall surface, which can be solved by a successive approximation method. Numerical examples show that the nonlinear effect decreases or increases the peak sound attenuation rate of the lowest mode depending upon the linear component of the resistance. The dependence of the attenuation spectrum on modal phase difference of multi-mode incident waves is heavily affected by the nonlinear effect. In the case of incident waves of multi-circumferential modes, different circumferential modes are generated by the nonlinear effect.

86-1451
Flow-Resonant Sound Interaction in a Duct Containing a Plate, II: Square Leading Edge
A.N. Stokes, M.C. Welsh
Commonwealth Scientific and Industrial Research Organization, Melbourne, Australia
J. Sound Vib., 104 (1), pp 55-73 (Jan 8, 1986) 14 figs, 16 refs

KEY WORDS: Ducts, Fluid-induced excitation, Sound waves, Wave propagation

The interaction between flow and flow-induced acoustic resonances near rigid plates with square leading edges located in a hard-walled duct is described. These plates generate Beta-mode acoustic resonances over several discrete ranges of flow velocity. A potential flow model for a plate with a square leading edge is developed and the acoustic power generated by vortices, which grow and shed from the leading edge, is calculated as they move through the resonant acoustic field. Vortices grow rapidly during the first half cycle and the vortex growth rate is quantified by using a Kutta condition. This model indicates that a major phase-dependent sound source occurs when a vortex passes the trailing edge of the plate. It is the remoteness of this source from the site at the leading edge where the sound affects the flow which makes possible the discrete resonance ranges.

DYNAMIC ENVIRONMENT

ACOUSTIC EXCITATION

86-1452
Concentrated Suspension Theory of Sound Attenuation in Marine Sediments — Linear Dependence of Absorption Coefficient on Frequency
Z.W. Qian
Academia Sinica, Beijing, China
J. Sound Vib., 103 (3), pp 427-436 (Dec 8, 1985)
4 figs, 16 refs

KEY WORDS: Underwater sound, Sound waves, Wave scattering, Wave attenuation, Statistical analysis

Statistical averages of acoustic scattering and attenuation in sea bed sediments, and of the corresponding sea bed absorption coefficients, are obtained. The multiple scattering interactions among the particles in concentrated suspension are taken into account. The suspensions are assumed to be a collection of spherical particles of various sizes, and for which the masses corresponding to various radii follow a normal distribution. The numerical results obtained show that the absorption coefficient has a linear dependence on frequency if there is a sufficiently broad distribution of the particle radii.

86-1453
Studies of Acoustical Fields Generated by Vibrating Structures with Applications to Noise Control by Design
Jiann-Kuo Jiang

Ph.D. Thesis, Stevens Inst. of Technology, 151 pp (1985) DA8522788

KEY WORDS: Machinery noise, Noise reduction, Design techniques

Machinery noise control problem can generally be classified as noise control at the source, noise control along the path, and noise control at the receiver. It is known that noise control at the source usually is the most desirable but difficult approach. The success of the efforts to control noise at the source certainly depends on the knowledge of the influence of various design parameters on the acoustical near and far fields. Vibrating structural components form one of the major source of noise in machinery. In this thesis theoretical and experimental studies on the acoustical fields due to various types of vibration structures are conducted. The studies are intended to obtain a better understanding of the influence of structural design parameters such as geometry and boundary effects on the acoustical near and far fields. The theoretical work is based on the boundary element method which can effectively deal with the boundary value problems especially associated with an infinite domain. The experimental work was conducted (in an anechoic chamber) to measure the sound pressure levels in the acoustical field generated by various vibrating structures.

86-1454

Calculating Acoustic Power of Planar Radiators According to the Fourier Method (Die Berechnung der akustischen Leistung ebener Strahler nach der Fourier-Methode)

H. Fleischer, V. Axelrad
Universität der Bundeswehr Munchen, Munich, Fed. Rep. Germany
Acustica, 59 (1), pp 42-53 (Nov 1985) 11 figs, 19 refs (in German)

KEY WORDS: Sound pressure, Fourier analysis

The Fourier method is applied to the calculation of acoustic power. The approach used is equivalent to determining complex power on the surface of the baffled radiator. In contrast to conventional methods, however, all operations are performed in the spatial Fourier domain. The following steps are done: After having transformed the given two-dimensional velocity distribution into Fourier domain, the amplitude spectrum is squared and then weighted by a transfer function. Numerical difficulties caused by using discrete spectra are overcome by introducing an appropriate attenuation factor. Integration in the Fourier domain of the real part yields resistive power, of the imaginary part reactive power. Comparisons of our results, obtained with a personal computer with values known from the literature, reveal good agreement. The Fourier method has the essential advantages of, not only dramatically diminishing the time of computation, but above all, making physical relationships transparent.

86-1455

On the Prediction of Impact Noise, X: The Design and Testing of a Quietened Drop Hammer

E.J. Richards, I. Carr
Univ. of Southampton, Southampton, England
J. Sound Vib., 104 (1), pp 137-164 (Jan 8, 1986) 21 figs, 8 tables, 13 refs

KEY WORDS: Drop tests (impact tests), Noise reduction

Part V in this series showed that the technique of predicting overall noise levels from vibration levels in a drop hammer produces surprisingly accurate results, allowing a good estimate of the contribution of each component to the overall noise. An exact one-third scale replica of an existing drop hammer was built for experimental purposes. On this particular drop hammer acceleration noise and ringing noise were both shown to be significant in terms of energy, unlike most other impact-related machinery noise, where ringing noise dominates. The work reported in this paper concerns a second model drop hammer which has replaced the first, incorporating maximized damping and isolation to reduce ringing noise. Predicted noise energy levels have been compared with measured noise energy levels at each stage of development, and the agreement between the two is consistently good.

86-1456

Recent Research on Turbulent Flow Noise Mechanisms

D.F. Long, R.E.A. Arndt
Univ. of Minnesota, Minneapolis, MN
Shock Vib. Dig., 17 (12), pp 7-15 (Dec 1985) 2 figs, 32 refs

KEY WORDS: Noise generation, Turbulence, Reviews

This article is concerned with the pressure field generated by large-scale coherent motions in turbulent flows. A general decomposition is discussed that evaluates the magnitude of the coherence in an unbiased way. This tool is described in terms of two flows of current interest, jets and boundary layers.

SHOCK EXCITATION

86-1457
Impact Responses of Multi-Body Systems with Consistent and Lumped Masses
Y.A. Khulief, A.A. Shabana
Univ. of Illinois, Chicago, IL
J. Sound Vib., 104 (2), pp 187-207 (Jan 22, 1986) 13 figs, 3 tables, 26 refs

KEY WORDS: Multibody systems, Impact response

A method is presented for the dynamic analysis of inertia-variant constrained mechanical systems of interconnected rigid and flexible components which may be impacting on one another. The flexible bodies are permitted to undergo large angular rotations. Elastic coordinates of flexible components are described by using sets of shape functions or shape vectors, resulting in consistent or lumped mass formulation that account for the nonlinear inertia coupling between the reference motion and elastic deformations. The consistent formulation allows the use of the Rayleigh-Ritz method or the finite element method, while the lumped mass formulation allows the direct use of assumed shape vectors or experimentally identified data.

86-1458
An Experimental Technique to Study Impulse-Wave Propagation in Materials
S. Yazdani-Ardakani, S.K. Kesavan, M.L. Chu
Univ. of Akron, Akron, OH
Exptl. Tech., 10 (1), pp 30-32 (Jan 1986) 6 figs, 5 refs

KEY WORDS: Wave propagation, Impulse response, Hopkinson bar technique

Dynamic characteristics of materials are of interest in a variety of industrial and biomechanical applications. A variety of techniques have been devised to study basic dynamic material properties. From several articles, one gathers that impulse-wave propagation tests are a popular means for dynamic material characterization. In this paper, we present an experimental technique which can be used to study impulse-wave propagation in materials. This technique uses a mechanical shaker to subject a vertically mounted specimen to impulsive forces. It is similar in principle to the Hopkinson's pressure-bar procedure.

86-1459
Response of Linear Structures to Nonstationary Excitations
B. Riaz
Ph.D. Thesis, Cornell Univ., 150 pp (1985) DA8525781

KEY WORDS: Single degree of freedom systems, Multidegree of freedom systems, Random vibrations, Seismic excitation

Seismic design generally involves dynamic analyses and is based on the peak structural response. Due to the limited information on the details of future seismic excitation, probabilistic models can provide realistic representation for seismic ground motion. Method of random vibration or simulation can be applied to determine the response of structures to random load processes. This work applies the theory of random vibration to analyze responses of linear single and multidegree of freedom systems to seismic excitation. The multidegree of freedom systems are assumed to have either proportional or nonproportional damping. Nonproportional damping is needed to model equipment-structure systems subjected to single or multiple inputs.

86-1460
Development of Substructuring Techniques for On-Line Computer Controlled Seismic Performance Testing
S.N. Dermitzakis
Ph.D. Thesis, Univ. of California, Berkeley, 151 pp (1985) DA8524928

KEY WORDS: Seismic response, Substructuring methods, Pseudodynamic testing method

Application of substructuring concepts to on-line computer controlled (pseudodynamic) testing is developed so that analytical subassemblages can be combined with a physical test assemblage to simulate the seismic response of the complete system. Numerical algorithms are developed to carry out analytical substructuring. Their reliability is investigated by means of pseudodynamic tests of several specimens. The results of these tests are presented and discussed and their correlation with analytical simulations is evaluated.

86-1461
Cumulative Damage of Structures Subjected to Response Spectrum Consistent Random Processes
G.D. Jeong
Ph.D. Thesis, California Inst. of Technology, 103 pp (1985) DA8519545

KEY WORDS: Seismic response, Steel, Reinforced concrete

A theoretical analysis of the effect of duration on the damage of structures subjected to earthquakes is presented. Earthquake excitation is modeled as a nonstationary random process. Estimates of the first-passage probability of a simple oscillator are employed to choose modulated Gaussian random processes consistent with a prescribed response spectrum. The response spectrum is assumed to be specified independent of the duration. Expressions for the mean damage of a structure are derived using an approach similar to the Miner-Palmgren rule for failure caused by cyclic loads. The expected damage expressions are then evaluated for a structure subjected to modulated Gaussian random processes of varying duration. Two types of structures are examined: a steel structure and a reinforced concrete structure. Results are presented for systems with constant linear stiffness and a particular form of softening behavior. The nonlinearity of the softening system is accounted for by statistical linearization. The level of expected damage is found to be a strong function of both the duration of the excitation and the ductility of the response.

86-1462
Evaluation of Method for Dynamic Impact Testing of Gypsum Concrete
B.C. Davis, S.E. Grinnell, L.I. Starrh
Lawrence Livermore National Lab., Lawrence, CA
Rept. No. UCRL-93305, CONF-850953-7, 23 pp (Sept 1985) (Symp. Containment of Underground Nuclear Explosions, Idaho Falls, ID, Sept 10, 1985) DE85018186/GAR

KEY WORDS: Concrete, Impact tests

Gypsum concrete plugs are now in use, and light-weight gypsum concrete plugs are being considered for use as part of the stemming materials put in emplacement holes for the Department of Energy's Nevada Test Site. The behavior of these concretes, under dynamic loading, needs to be characterized. This report describes two series of impact tests that were conducted: the first, to evaluate the merits of the test and the measurement method; the second, to evaluate the material properties under dynamic loading.

86-1463
A Numerical Model of Acoustic Choking, Part II: Shocked Solutions
N.J. Walkington, W. Eversman
Univ. of Missouri-Rolla, Rolla, MO
J. Sound Vib., 104 (1), pp 81-107 (Jan 8, 1986)
13 figs, 19 tables, 23 refs

KEY WORDS: Shock waves, Sound waves

The one dimensional equations of gas dynamics are used to model subsonic acoustic choking. This model can accommodate nonlinear distortion of waves and the eventual formation of shock waves. Several finite differencing schemes are adapted to obtain solutions. The results obtained with the various schemes are compared with the asymptotic results available. The results suggest that no one finite differencing scheme gives solutions significantly better than the others and that most of the difference solutions are close to the asymptotic results. If the acoustic shock wave is sufficiently strong it almost annihilates the acoustic wave; in this situation numerical errors may dominate the results. Such solutions involve very large acoustic attenuations.

86-1464
Decay of Strong Shocks in Non-Linear Elasticity
M. Elzanowski, M. Epstein
Univ. of Calgary, Calgary, Alberta, Canada
J. Sound Vib., 103 (3), pp 371-378 (Dec 8, 1985)
2 figs, 2 tables, 9 refs

KEY WORDS: Shock waves, Elastic media

The method of singular surfaces is used to develop a numerical technique for calculating the decay and growth of the amplitude of shock waves in nonlinear elastic materials. No restrictions are imposed on the magnitude of the initial conditions, which results in a coupling between the shock and the induced waves, governed by an infinite system of ordinary differential equations. Numerical examples illustrate the applicability of the technique in highly nonlinear situations.

86-1465
The Shock Spectrum Dip Effect
G.J. O'Hara, P.F. Cunniff
Univ. of Maryland, College Park, MD
J. Sound Vib., 103 (3), pp 311-321 (Dec 8, 1985)
15 figs, 1 table, 7 refs

KEY WORDS: Shock resistant design, Shock response spectra, Structure foundation interaction

The shock spectrum dip effect, for a structure subject to transient excitation, is investigated, with use being made of controlled laboratory shock experiments. A rough understanding of the phenomenon is provided by observing that a

structure on a nonrigid foundation tends to act as a dynamic vibration absorber for frequencies corresponding to its fixed base natural frequencies. The two mathematical models used provide information helpful in distinguishing between ordinary shock spectra and design shock spectra, and thus in developing shock design values for future structures.

VIBRATION EXCITATION

86-1466
Phase Plane for Narrow Band Random Excitation of a Duffing Oscillator
H.G. Davies, D. Nandlall
Univ. of New Brunswick, Fredericton, Canada
J. Sound Vib., 104 (2), pp 277-283 (Jan 22, 1986) 3 figs, 11 refs

KEY WORDS: Duffing oscillators, Random excitation, Mean square response

The response of a Duffing oscillator to narrow band random excitation is considered. It is shown that multiple values of the response can occur at some frequencies for very narrow excitation bandwidths, but these reduce to a single value as the bandwidth is increased. Time histories of quantities such as mean square displacement are obtained from the time dependent Fokker Planck equation. Smoothed time histories of mean square velocity and displacement are plotted on a phase plane. The phase plane can show either one sink, or two sinks and a saddle point as in the sinusoidal case, but again, excitation bandwidth determines whether or not multiple sinks occur.

86-1467
Internal Resonances Effects — Simulation Versus Analytical Methods Results
J. Bajkowski, W. Szemplińska-Stupnicka
Polish Academy of Sciences, Warsaw, Poland
J. Sound Vib., 104 (2), pp 259-275 (Jan 22, 1986) 9 figs, 32 refs

KEY WORDS: Internal resonance, Analog simulation, Ritz method, Averaging techniques

In this study of internal resonance effects in a two-degree-of-freedom system with cubic nonlinearity attention is focussed on behavior of the system, as examined with the aid of an analog computer, and on an adequacy of approximate analytical methods: the averaging method and the Ritz method. It is shown that while the averaging method fails to predict the behavior of the system the Ritz method gives results surprisingly close to those obtained by the simulation method. The results indicate that the internal resonance can be responsible for occurrence of two-frequency oscillations with the amplitude of the subharmonic tone nearly 10 times higher than the amplitude of the fundamental harmonic component.

86-1468
Free Vibration of Combined Dynamical Systems
J.W. Nicholson, L.A. Bergman
Shell Development Co., Houston, TX
ASCE J. Engrg. Mech., 112 (1), pp 1-13 (Jan 1986) 2 figs, 2 tables, 24 refs

KEY WORDS: Harmonic response, Natural frequencies, Mode shapes

A method for analyzing the free vibration of combined linear undamped dynamical systems attached at discrete points is shown. The method uses separation of variables to exhibit the harmonic motion of the system and to derive a generalized differential equation for the normal modes. Green's functions for the vibrating component systems are used to solve the generalized differential equation and derive the characteristic equation for the natural frequencies of the system. The characteristic equation can then be solved for the exact natural frequencies and exact normal modes. The method is demonstrated for two types of dynamical systems involving beams and oscillators. For two particular systems, approximate natural frequencies determined through a Galerkin's method and the finite element method are compared to the exact natural frequencies. The generalized orthogonality relation for each system is derived.

86-1469
Excitation of Instability Waves
W. Bechert
Institut für Experimentelle Strömungsmechanik der Deutschen Forschungs und Versuchsanstalt für Luft und Raumfahrt, Berlin
Z. Flugwiss. Weltraumforsch., 9 (6), pp 356-361 (Nov/Dec 1985) 4 figs, 33 refs

KEY WORDS: Fluid-induced excitation, Random excitation

A brief survey is given on artificial excitation of instability waves in parallel flows. There are basically two categories of unstable flows: (a) convectively unstable and (b) absolutely unstable flows. The perturbation level in convectively

unstable flows, e.g., boundary layers and most free shear flows, depends on the excitation only. On the other hand, absolutely unstable flows, e.g., wake flows and hot jets, do maintain fluctuations independent of any exterior excitation. Finally, effects of non-parallel mean flow and of varying boundary conditions on instability wave excitation are discussed.

86-1470
The Variational and Virial-like Theory of Oscillations and Stability of Non-conservative and/or Non-linear Mechanical Systems
J.G. Papastavridis
Georgia Institute of Technology, Atlanta, GA
J. Sound Vib., 104 (2), pp 209-227 (Jan 22, 1986) 34 refs

KEY WORDS: Hamiltonian principle, Nonlinear systems, Variational methods

This paper presents the general theory and some applications of Hamiltonian action and virial-like methods to the exact and/or approximate study of the periodic solutions of nonconservative and/or nonlinear, but holonomic, oscillators. Specifically, the first (theoretical) part covers a generalization of "Hamilton's law of varying action", to include variable time-endpoints (i.e., frequency variations) and variable system parameters. A general formulation of the "virial" theorem and its use in determining the stability/instability of given oscillatory motions is covered. Applications of the above (of the Rayleigh-Ritz type) to certain systems are then presented. Comparison of the method with other existing ones, and related open problems (such as limit-cycle stability), are finally discussed.

86-1471
The Influence of an Internal Resonance on Non-linear Structural Vibrations Under Combination Resonance Conditions
D.T. Mook, N. HaQuang
Virginia Polytechnic Institute and State Univ., Blacksburg, VA
J. Sound Vib., 104 (2), pp 229-241 (Jan 22, 1986) 9 figs, 5 refs

KEY WORDS: Internal resonance

A system of equations with quadratic and cubic nonlinearities is considered. This system models structural elements which have initial curvature and also exhibit mid-surface stretching during motion. The response to a simple-harmonic external excitation is analyzed when the excitation frequency is near the sum of two natural frequencies. If the system possesses the internal resonance, the response may be significantly reduced. Also, the energy may shift periodically between the first and second modes instead of approaching a steady state. The results are obtained by the method of multiple scales and are presented as plots of modal amplitudes versus excitation amplitude, excitation frequency, detuning of the internal resonance, and time.

86-1472
On the Resonant Component of the Response of Single Degree-of-Freedom Systems Under Random Loading
M. Ashraf Ali, P.L. Gould
Washington Univ., St. Louis, MO
Engrg. Struc., 7 (4), pp 280-282 (Oct 1985) 1 fig, 1 table, 6 refs

KEY WORDS: Resonant response, Single degree of freedom systems, Wind-induced excitation

A simple expression for the resonant component of the response variance of a single degree-of-freedom system under wind pressure loading is derived. For slowly varying excitation spectral densities, low structural damping and relatively wide excitation frequency bands, the expression gives a good estimate of the response variance. The derivation substantiates a frequently used approximation of the analysis of single-degree-of-freedom system under wind loading.

MECHANICAL PROPERTIES

DAMPING

86-1473
Dynamics of Viscoelastic Structures
K.J. Buhariwala
Ph.D. Thesis, Univ. of Toronto, Canada (1985)

KEY WORDS: Viscoelastic damping, Polymers, Composite materials

A general method for modeling energy dissipation in dynamical systems is presented. The work is primarily concerned with a damping model based on viscoelastic assumptions motivated by the concern for analyzing structures composed of fibre reinforced polymeric composite materials. A brief review of linear viscoelasticity is presented. Recommendations and extensions for

further investigation pertaining to the dynamics of viscoelastic structures are included.

86-1474
Predictions of Total Loss Factors of Structures, Part II: Loss Factors of Sand-filled Structure
J.C. Sun, H.B. Sun, L.C. Chow, E.J. Richards
Univ. of Southampton, Southampton, England
J. Sound Vib., 104 (2), pp 243-257 (Jan 22, 1986) 10 figs, 14 refs

KEY WORDS: Loss factors, Energy dissipation, Sand, Plates, Tubes

An investigation has been carried out in which sand was added to damp plates and tubes. A formula for calculating the loss factors of these configurations has been derived by using Statistical Energy Analysis (SEA) on the assumption that energy transmission between the structures and the sand space has an analogy with that between a structure and a surrounding medium (air or water) and that theories normally applicable to room acoustics are valid in sand spaces. A series of experiments has been carried out on the various structures filled with sand. Agreement between the measured and calculated results is reasonable and sufficient to permit the diagnostic prediction of damping in, and the noise from, complex structures with sand filled (fully or partially) cavities.

86-1475
Quantification of the Extent of Non-Proportional Viscous Damping in Discrete Vibratory Systems
G., Prater, Jr., R. Singh
Ohio State Univ., Columbus, OH
J. Sound Vib., 104 (1), pp 109-125 (Jan 8, 1986) 11 figs, 26 refs

KEY WORDS: Viscous damping

The primary objective of this paper is to present several numerical indices developed to determine quantitatively the extent of nonproportional damping present within a discrete vibratory system. A total of five distinct indices are considered. Two of these are based on the complex modes of a generally damped system, and three are based on the configuration of the system damping matrix after transformation into real normal coordinates. Each index has been normalized so that it assumes values between zero (proportional damping case) and one. Application of the indices is illustrated through a four degree of freedom system example problem. As part of this exercise, an effort is made to relate the magnitudes of the indices to the frequency response errors induced by two proportional damping approximations often found in the literature.

86-1476
Dynamics of Viscoelastic Structures — A Time-Domain, Finite Element Formulation
D.F. Golla, P.C. Hughes
University of Toronto, Canada
J. Appl. Mech., 52 (4), pp 897-906 (Dec 1985) 2 figs, 4 tables, 9 refs

KEY WORDS: Viscoelastic damping, Time domain method, Finite element technique

Mathematical models of elastic structures have become very sophisticated: given the crucial material properties (mass density and the several elastic moduli), computer-based techniques can be used to construct exotic finite element models. By contrast, the modeling of damping is usually very primitive, often consisting of no more than mere guesses at "modal damping factors". The aim of this paper is to raise the modeling of viscoelastic structures to a level consistent with the modeling of elastic structures. Appropriate material properties are identified which permit the standard finite element formulations used for undamped structures to be extended to viscoelastic structures.

86-1477
Experimental-Theoretical Study of Velocity Feedback Damping of Structural Vibrations
G.R. Skidmore
Ph.D. Thesis, Virginia Polytechnic Inst. and State Univ., 109 pp, (1985) DA8521353

KEY WORDS: Active damping

This study concerns the active damping of structural vibrations through the application of various forms of velocity feedback control. Active damping will be required for large space structures which are performance-sensitive to motion or inaccurate pointing. Several control forms, including modal-space active damping and direct rate feedback, are analyzed theoretically, and three laboratory models are described. A previous, unsuccessful attempt at control is reviewed and explained. The remaining control forms developed in the theoretical section were implemented successfully and the results compare favorably with theoretical predictions. Each control form is analyzed relative to its own merits and in comparison with other methods. An important point is the stability assured by a dual (colocated) configuration of velocity sensors

and control force actuators. Modal-space active damping is shown to be an effective control method with predictable performance in controlled modes and beneficial spillover into residual (non-controlled) modes.

86-1478
Multiunit Impact Damper — Re-examined
C.N. Bapat, S. Sankar
Concordia Univ., Montreal, Quebec, Canada
J. Sound Vib., 103 (4), pp 457-469 (Dec 22, 1985) 9 figs, 1 table, 13 refs

KEY WORDS: Coulomb friction, Impact dampers

The multiunit impact damper with Coulomb friction has been studied theoretically and by simulation on the digital computer. It is found that the performance of a single damper is retained when it is replaced by a multi-unit damper with a moderate number of units having the same total mass, coefficients of Coulomb friction and restitution, and gap. However, the velocity discontinuity of the damped system is reduced significantly. In periodic motion with identical units, each unit exhibiting two equispaced impacts/cycle motion, impacts occur in clusters and are not uniformly distributed in time. The effect of the number of units and Coulomb friction on the amplitude reduction, velocity discontinuity at impact and temporal distribution of impacts is considered.

86-1479
Sweep Technique to Measure the Relative Performance of Dampers
A. Jamaleddine
Institut de Recherche d'Hydro-Quebec, Varennes, Quebec, Canada
Exptl. Mech., 25 (4), pp 354-359 (Dec 1985) 6 figs, 11 refs

KEY WORDS: Dampers

The sweep technique described in this paper represents a new method for measuring the relative performance of different dampers. Based on laboratory measurements, the technique is easy to use and keeps test execution time to a minimum. It also allows measurement of the relative performance of nonlinear dampers for which it is difficult to derive the analytical expression for their mechanical impedance. In addition to describing the test setup, the paper also presents results obtained from the application of this technique to four types of commercial dampers.

86-1480
Dynamic Analysis of Nonclassically Damped Systems
C.E. Ventura Z.
Ph.D. Thesis, Rice Univ., 203 pp (1985) DA8517238

KEY WORDS: Damped structures, Modal superposition method, Base excitation, Discrete Fourier transform

The objectives of the studies reported in this dissertation are: to develop improved techniques for evaluating the dynamic response of viscously damped linear systems, and to contribute concepts and information which will lead to an improved insight into the dynamic response of such systems.

FATIGUE

86-1481
Mixed-Mode Failure of Composite Laminates with Cracks
L.M. Daniel
Illinois Institute of Technology, Chicago, IL
Exptl. Mech., 25 (4), pp 413-420 (Dec 1985) 15 figs, 10 refs

KEY WORDS: Fatigue life, Layered materials, Cracked media

The behavior of quasi-isotropic graphite/epoxy laminates with cracks subjected to various biaxial-stress field was studied experimentally. This was accomplished by uniaxial tensile loading of specimens with cracks of various orientations with the loading axis. It was found that the critical stress-intensity factor, based on a projected crack length increased by a characteristic damage dimension, is nearly constant with stress biaxiality and initial crack length.

ELASTICITY AND PLASTICITY

86-1482
A Rate Dependent Model for Plain Concrete Under Dynamic Multiaxial Loads
H.E. Delgado-Saavedra
Ph.D. Thesis, Columbia Univ., 78 pp (1985) DA8523151

KEY WORDS: Concrete, Elastic properties, Viscoplastic properties, Cyclic loading

A rate dependent model based on elasto/viscoplasticity theory has been proposed to simulate the behavior of concrete subjected to three dimensional dynamic states of stress and strain. Two surfaces in stress space were used to describe the material behavior: a discontinuity surface that plays the role of a yield surface, and a bounding failure surface which is essentially a damage monitoring device to control the failure stress level. The fluidity parameter of the basic elasto/viscoplasticity theory has been considered dependent on the elastic strain rate. The model has been combined with a crack monitoring algorithm, defined in terms of strains.

EXPERIMENTATION

MEASUREMENT AND ANALYSIS

86-1483
Strobed, Time-average Holographic Visualization of Loudspeaker Transient Vibrations
P. Perz
Adam Mickiewicz Univ., Poznan, Poland
J. Sound Vib., 103 (4), pp 509-518 (Dec 22, 1985) 4 figs, 1 table, 7 refs

KEY WORDS: Transducers, Transient vibrations, Holographic techniques

A method of holographic registration of the vibration distribution on the surface of a transducer excited with transient signals is presented. The transducer investigates is illuminated stroboscopically. The duration of the illuminating impulses are equal to the transducer's membrane vibration period. Thus the set of holograms registered at different times during the duration of the transient makes it possible to determine the time history of the vibration amplitude distribution. Results of applying this method to the investigation of the distribution of loudspeaker membrane vibrations are presented.

86-1484
Pulse and Time-Domain Measurements
R.A. Lawton, J.R. Andrews
National Bureau of Standards, Boulder, Co
IEEE, Proc., 74 (1), pp 77-81 (Jan 1986) 3 figs, 28 refs

KEY WORDS: Time domain method, Measurement techniques, Pulse excitation

A review of the state of the art and science of pulse parameter measurements is given including recent advances in the use of real-time oscilloscopes, waveform recorders, equivalent time sampling oscilloscopes, and counter timers in the measurement of repetitive and single transient signals. Recent advances in the use of artifact waveform standards and modern signal analysis techniques to compensate for measurement distortion are highlighted.

86-1485
Conversion of Frequency-Domain Data to the Time Domain
B. Ulriksson
Chalmers Univ., Gothenburg, Sweden
IEEE Proc., 74 (1), pp 74-77 (Jan 1986) 3 figs, 8 refs

KEY WORDS: Frequency domain method, Time domain method, Fast Fourier transform, Fourier series, Z-transform

The advantages and disadvantages of three different algorithms for transforming frequency-domain data to the time domain are reviewed. The algorithms are a direct computation of the Fourier series, the fast Fourier transform, and the chirp-z transform. It is concluded that the fast Fourier transform still has the advantage of speed, but the chirp-z transform offers some additional flexibility that makes it more useful in many applications.

86-1486
Processing Measurement Signals with High Resolution AD-Conversion (MeBsignalverarbeitung mit hochauflösender AD-Wandlung)
A. Klauer, M. Pandit
Universitat Kaiserslautern, Fed. Rep. Germany
Techn. Messen-TM, 52 (11), pp 404-410 (1985) 6 figs, 12 refs (in German)

KEY WORDS: Signal processing techniques, Digital filters

A concept for analog-digital conversion and digital filtering is proposed which allows the analog lowpass filter to be replaced by a digital lowpass filter and at the same offers a high resolution digital output independent of the conversion time.

86-1487
Digital Signal Processing in Vibration Analysis (Digitale Signalverarbeitung in der Schwingungsmeßtechnik)
J. Zaschel
Carl Schenk, Darmstadt, Fed. Rep. Germany
Techn. Messen-TM, 52 (11), pp 399-403 (1985) 3 figs, 24 refs (in German)

KEY WORDS: Signal processing techniques, Digital techniques, Digital filters

Measuring vibrations is related to various applications in the field and therefore correlated with a big variety of analyzing methods, which can be performed by numerous analog procedures. For some time past also digital methods of signal processing have been available for new applications, which is in the first place digital filtering. They are discussed related to vibration analysis with the aim of an overall presentation.

86-1488
On the Use of Fast Fourier Transforms When High Frequency Resolution is Required
R. Parker, S.A.T. Stoneman
Univ. College of Swansea, Swansea, Wales
J. Sound Vib., 104 (1), pp 75-79 (Jan 8, 1986) 1 table, 2 refs

KEY WORDS: Signal processing techniques, Fast Fourier transform

The paper gives a method of obtaining high frequency resolution of spectral peaks when time series data is transformed to the frequency domain by means of a simple Fast Fourier Transform.

86-1489
Spectral Analysis Using Number Theoretic Transforms with Fast Fourier Transform Implementation
R. Adhami
Ph.D. Thesis, Univ. of Alabama in Huntsville, 147 pp (1985) DA8519070

KEY WORDS: Spectrum analysis, Fourier transform

Transforms defined in the finite ring of integers (number theoretic transforms) have the cyclic convolution property and can, in some instances, be used to efficiently compute the cyclic convolution of discrete signals. With a basic knowledge of number theory, it can be shown that the discrete power spectrum may be obtained by computing a cyclic convolution. This new method of computing the discrete power spectrum, using number theoretic transforms, is implemented on a digital computer with an efficient algorithm similar to the radix-2 fast Fourier transform. The results are validated by comparison with a normalized/quantized discrete Fourier transform approach.

DYNAMIC TESTS

86-1490
Transient Excitations of Mechanical Vibrations in Testing Techniques (Transiente Anregungen von mechanischen Schwingungen in der Versuchstechnik)
H.G. Natke
Universität Hannover, Hannover, Fed. Rep. Germany
Techn. Messen-TM, 52 (11) pp 393-398 (1985) 16 figs, 12 refs (in German)

KEY WORDS: Vibration tests, Testing techniques, Transient excitation

Measuring techniques, in particular the techniques of measuring vibrations, cannot be performed without artificial excitation when the mechanical properties of technical structures have to be obtained experimentally. Starting with the development of the techniques of vibration testing and the classification of test signals, the properties of step-shaped and impulse-shaped test signals are discussed. The advantages and disadvantages of these artificial excitations are mentioned. Possibilities for realization are shown with the aid of practical examples. With the step-shaped signals the application of the relaxation step is observed on an off-shore platform and a reinforced concrete bridge. The realization and application of impulse-shaped artificial excitations are discussed with the examples: excitation of soil waves by an impulse hammer, vibration excitation of airplanes during flight by means of cartridges (repulsion), and vibration excitation of a bridge pylon as a result of blast pressure stress.

86-1491
Operations Manual for the Data Acquisition and Reduction System, Shock Laboratory Test Facility
E.L. Smith
Sandia National Labs., Albuquerque, NM
Rept. No. SAND-83-2177, 41 pp (Aug 1985) DE85016530/GAR

KEY WORDS: Test facilities, Shock tests, Data processing

This manual describes the operation of the new mini-computer-based data acquisition and reduction system for the Shock Laboratory Test Facility at Sandia National Laboratories. The system provides faster turnaround time and easier operation because of the availability of computer assess at each test location.

DIAGNOSTICS

86-1492
A Numerical Study of the Eigenparameters of a Damaged Cantilever
M.M.F. Yuen
Univ. of Hong Kong, Hong Kong
J. Sound Vib., 103 (3), pp 301-310 (Dec 8, 1985) 4 figs, 3 tables, 10 refs

KEY WORDS: Cantilevers, Failure detection, Finite element technique

When a structure is subjected to damage, its dynamic response changes, characterized by shifts in the eigenvalues and modifications of the eigenvectors. Considerable effort has been put into investigating the relationship between the damage location, the damage size and the corresponding changes in the eigenparameters. In most cases, emphasis has been on using the shift in eigenvalues as a means of determining the damage location, and the information derived from the change in eigenvectors has largely remained obscure. In this paper a systematic study is presented of the relationship between damage location, damage size and the changes in the eigenvalues and eigenvectors of a cantilever when subjected to damage. A finite element model of a uniform cross sectioned cantilever was chosen to provide data for analysis. The changes in the eigenvalues and eigenvectors are shown to follow a definite trend in relations to the location and extent of damage.

86-1493
Fault Analysis in Dynamic Systems with Application to Reciprocating Combustion Engines
A.A. Fahs
Ph.D. Thesis, Wayne State Univ., 205 pp (1985) DA8514129

KEY WORDS: Diagnostic techniques, Failure detection, Reciprocating engines

The problem of fault analysis can be divided into three parts: fault detection, diagnosis and location, and reconfiguration or repair. This study introduces two general approaches for fault analysis in dynamic systems, which are described by ordinary differential equations. The first approach requires continuous monitoring of the output variables of the system. Under normal conditions they deviate from this nominal history. Fault analysis is accomplished by measuring these deviations.

86-1494
A Signal Processing Technique for Detecting Local Defects in a Gear from the Signal Average of the Vibration
P.D. McFadden, J.D. Smith
Aeronautical Research Labs., Melbourne, Victoria, Australia
IMechE, Proc., Part C: Mech. Engrg. Sci., 199 (C4) pp 287-292 (1985) 5 figs, 3 refs

KEY WORDS: Diagnostic techniques, Failure detection, Gears, Signal processing techniques, Fatigue life

An approximate digital signal processing technique is presented which can assist in the early detection of local defects such as fatigue cracks in gears by enhancing the changes which these defects produce in the signal average of the vibration of the gear. The technique is demonstrated by the identification of an early fatigue crack in a helicopter gear. The importance of phase modulation in the detection of defects is indicated.

BALANCING

86-1495
A Condition and Performance Monitoring System with Application to U.S. Navy Ship Operations
R.E. Reid
Univ. of Illinois, Urbana-Champaign, IL
Naval Engr. J., 97 (7), pp 29-38 (Nov 1985) 10 figs, 36 refs

KEY WORDS: Monitoring techniques, Ships, Microcomputers

The paper describes a microprocessor based onboard automatic ship condition/performance

monitoring system. The capabilities of the system for achievement of improved maintenance management and increased operational standard are presented. By the design principles employed, and the system implementation as a distributed digital processing system, it is shown that the technology described is compatible with current U.S. Navy goals both for onboard control and surveillance systems and for reduction in the maintenance costs necessary to achieve high availability and performance of its ship.

86-1496

Diagnostic Monitoring of Rolling-Element Bearings by High-Frequency Resonance Technique

H. Prashad, M. Ghosh, S. Biswas
Bharat Heavy Electricals, Ltd., Hyderabad, India

ASLE, Trans., 28 (4), pp 439-448 (Oct 1985) 9 figs, 5 tables, 7 refs

KEY WORDS: Monitoring techniques, High frequency resonance technique, Rolling contact bearings

In the present work, investigations by high-frequency resonance technique for diagnosis of defect frequencies of rolling-element bearings are reported. Raw vibration signature of the bearings at different speeds of operation has been demodulated. Envelope detected spectrum is analyzed to evaluate various defect frequencies and their energy levels. Experimentally evaluated frequencies are compared with theoretically determined defect frequencies. These frequency values and their energy levels are used to monitor intrinsic condition of bearings as well as to establish severity of existing/developed defects in the bearings. Relative comparison of bearings of the same type are made at various operating speeds under identical conditions of operation on the basis of identified defect frequencies and severity of defects. The paper gives a realistic approach to monitor intrinsic condition of a bearing. Investigations given in the paper may have a potential for performance evaluation and may act as a reliable tool to establish safe limit for bearing operation.

86-1497

Comparative Holographic Interferometry: A Nondestructive Inspection System for Detection of Flaws

P.K. Rastogi
Swiss Federal Inst. of Tech., Lausanne, Switzerland

Exptl. Mech., 25 (4), pp 325-337 (Dec 1985) 14 figs, 15 refs

KEY WORDS: Monitoring techniques, Holographic techniques, Interferometric techniques

Comparative holographic interferometry addresses a key problem of nondestructive evaluation: comparison of the resistance to strength in real time of two nominally identical specimens. After outlining the basis of comparative holography in flaw detection, the present paper reports on some new and complementary developments in comparative holographic interferometry. The proposed systems stand out by their ability to store the master displacement field in the interferometric setup. The integration of the storage capacity in the instrument considerably augments its potential in nondestructive routine inspection tasks. The visual display of the fringes contouring the difference in mechanical response is shown to improve considerably with the addition of auxiliary phase difference satisfying certain conditions. Methods for the generation of corresponding fringes are considered and their localization investigated in brief. Particular attention is devoted to the formation of the holographic moire fringes. The influence of system misalignment on the moire-fringe interpretation is examined. A potential application of comparative holography to the quantitative evaluation of fatigue is described. Experimental evidence supporting the operational feasibility of the technique along with the results obtained in application to flaw detection are finally presented.

86-1498

Acoustic Emissions from Wire and Synthetic Ropes

P.A.A. Laura
Institute of Applied Mechanics, Puerto Belgrano Naval Base, Argentina

Shock Vib. Dig., 17 (12), pp 3-5 (Dec 1985) 8 refs

KEY WORDS: Cables, Wire, Acoustic Emission, Monitoring techniques, Reviews

The rupture of mechanical cables used in towing operations, remote control of equipment, and salvage operations can result in loss of both life and equipment. Accordingly, reliable and simple methods to assess the structural integrity of mechanical cables are of utmost importance. The present paper is a brief review of applications of the acoustic emission method from the point of view of the nondestructive evaluation of wire and synthetic ropes and monitoring their mechanical status while in operation.

ANALYSIS AND DESIGN

ANALYTICAL METHODS

86-1499
On the Second Variations for the Stress Wave Problem Using the Euler-Lagrange and Adjoint Formulations
C.N. Shen
U.S. Army Armament, Munitions, and Chemical Command, Watervliet, N.Y.
J. Sound Vib., 104 (1), pp 41-54 (Jan 8, 1986) 5 figs, 11 refs

KEY WORDS: Euler-Lagrange equation, Stress waves, Wave propagation, Shock waves

Dynamical stress behaviors and shock transients in mechanics are important subjects to be studied. The use of the finite element method based on developed algorithms from the variational principle can give direct numerical solutions for partial derivations of the function in these problems. Many researchers have found it difficult to apply the finite element method to an hyperbolic type partial differential equation (PDE). The Galerkin method and the like have been used instead. The author has reported previous attempts to solve these hyperbolic type PDE's by employing variational principles in a number of papers. It is the purpose of this paper to show that under certain conditions the stationary values are strong extremals, not saddle points. This is equivalent to requiring that the second variations of the functional be positive semidefinite with discontinuities in the partials.

86-1500
A Study of Reduction Methods in Nonlinear Dynamics
J.L.M. Clemente
Ph.D. Thesis, Duke Univ., 132 pp (1984) DA8516844

KEY WORDS: Reduction methods

The effect of reducing the number of variables in a system of first-order coupled differential equations is studied. Reduction is desirable when the number of equations is too high and its numerical solution very expensive. Four reduction methods employed for reducing the number of variables are studied, namely the Guyan-Irons, the Ritz, the eigenvectors expansion and the path derivatives expansion methods. Each method uses a different reduction matrix, which are redefined for the first-order problem.

86-1501
A Bond Graph Based Analysis of Coupled Vibratory Systems Taking Advantage of the Dual Formulation
B. Samanta, A. Mukherjee
Indian Institute of Technology, Kharagpur, India
J. Franklin Inst., 320 (3/4), pp 111-131 (Sept/Oct 1985) 5 figs, 3 tables, 10 refs

KEY WORDS: Bond graph technique, Complex structures

A technique is presented to study the overall characteristics of complex dynamic systems from those of the subsystems which are easy to model individually. The complex system is divided into a number of simple subsystems each of which may be represented by using either position-velocity or impulse-force descriptions. The appropriate boundary conditions are assigned at the interfaces. The subsystems are then interpreted in the form of bond graphs using a finite mode representation. These bond graphs are coupled through proper elements such that the conditions of equilibrium and continuity at the interfaces are preserved. The overall system dynamics are studied from the resulting bond graph. The procedure is illustrated through simple examples.

86-1502
Finite Element Method Analysis of Nonlinear Continua Using the Stochastic Equivalent Linearization Technique
I. Simulescu
Ph.D. Thesis, Columbia Univ., 102 pp (1985) DA8523240

KEY WORDS: Eigenvalue problems, Finite element technique, Equivalent linearization method

A finite element formulation for a class of nonlinear viscoelastic continua subjected to stochastic excitation has been developed by means of a stochastic equivalent linearization technique. The nonlinear viscoelastic properties of the continua are modeled in terms of the constitutive equation which linearly involves the hysteretic tensor and of the auxiliary equation which describes a nonlinear relationship among the strain and hysteretic tensors and their time derivatives. This auxiliary equation is linearized with the aid of a stochastic linearization technique which minimized the expected value of the square of the difference between the nonlinear and linear-

ized auxiliary equations. The linearized boundary value problem then involves a set of two linearization coefficients which are functions of space and time. With the aid of the weighted residuals method, the boundary value problem developed for the continuum is transformed into that in the finite element formulation.

86-1503
Automated Dynamic Analytical Model Improvement for Damped Structures
J.S. Fuh, A. Berman
Kaman Aerospace Corp., Bloomfield, CT
Rept. No. R-1810, NASA-CR-177945, 35 pp (Sept 1985) N85-34425/7/GAR

KEY WORDS: Damped structures, Mathematical models

A method is described to improve a linear nonproportionally damped analytical model of a structure. The procedure finds the smallest changes in the analytical model such that the improved model matches the measured modal parameters.

PARAMETER IDENTIFICATION

86-1504
Parameter Identification and State Estimation of Constrained Systems
Tien-Li Chia
Ph.D. Thesis, Case Western Reserve Univ., 138 pp (1985) DA8525239

KEY WORDS: Constrained structures, Parameter identification technique

Recursive algorithms are developed which estimate system parameters or states (or both) that arise from systems possessing known linear constraints on these parameters or states. These recursive estimates satisfy the known constraints at each time. The basic approach is to correctly project onto the constraint surface the results of the unconstrained least squares estimator (for parameter identification), Kalman filter (for state estimation) or modified extended Kalman filter for joint estimation). Correct projection involves an orthogonal projection under the appropriate coordinate transformation. The statistical properties of these estimators of constrained systems are then examined in detail. In this work, all of the constrained identification and estimation problems are treated in the same framework.

DESIGN TECHNIQUES

86-1505
Modal Analysis — An Old Procedure with a New Look
K.K. Stevens
Florida Atlantic Univ., Boca Raton, FL
Mech. Engrg., 107 (12), pp 52-56 (Dec 1985) 6 figs

KEY WORDS: Modal analysis, Design techniques

No longer is it only possible to deal with vibrations after the fact. This article describes, with the help of modal analysis, the desired dynamic characteristics that can be designed into a system.

AUTHOR INDEX

Adhami, R..... 1489
Alam, N..... 1429
Alarcon, L.F..... 1379
Alfred, J.R..... 1410
Andersen, P..... 1422
Anderson, C.W..... 1440
Anderson, M.S..... 1417
Andrews, J.R..... 1484
Arndt, R.E.A..... 1456
Ashraf Ali, M..... 1472
Asnani, N.T..... 1429
Aubert, A.C..... 1406
Avanessian, V..... 1441
Axelrad, V..... 1454
Baharlou, B..... 1430
Bajkowski, J..... 1467
Banerjee, P.K..... 1385
Bapat, C.N..... 1478
Baron, J..... 1433
Beards, C.F..... 1403
Bechert, W..... 1469
Bendimerad, M.F..... 1387
Bergman, L.A..... 1416, 1425, 1468
Berman, A..... 1503
Berman, A.S..... 1365
Bert, C.W..... 1445
Bertram, A.L..... 1440
Bettles, R.W..... 1409
Bickford, W.B..... 1446
Biswas, S..... 1496
Buhariwala, K.J..... 1473
Bux, S.L..... 1414
Cabelli, A..... 1449
Carr, I..... 1455
Caseiro, C.A..... 1395
Chang, I.-J..... 1448
Chang, Tai-Ping..... 1380
Chapman, D.A..... 1409
Cheng, C.A..... 1365
Chia, Tien-Li..... 1504
Chiba, M..... 1443
Chory, A..... 1368
Chow, L.C..... 1474
Chu, Chien-Tsun..... 1388
Chu, M.L..... 1458
Clemente, J.L.M..... 1500
Crawley, E.F..... 1406
Cruz, E..... 1381
Cummings, A..... 1448
Cunniff, P.F..... 1465
Dakoulas, P.C..... 1391
Daniel, I.M..... 1481
Datta, S.K..... 1447
Davies, H.G..... 1466
Davis, B.C..... 1462
DeBejar, L.A..... 1382
Delgado-Saavedra, H.E..... 1482
Denman, E.D..... 1394
Dermitzakis, S.N..... 1460
Dong, S.B..... 1441
Ellingwood, B..... 1378
Elzanowski, M..... 1464
Epstein, M..... 1464
Ercoli, L..... 1427, 1433
Etison, I..... 1408
Eversman, W..... 1463
Fahs, A.A..... 1493
Fleischer, H..... 1454
Fok, Ka-Lun..... 1389
Foltz, J.V..... 1440
Forouhar, F..... 1444
France, D..... 1366
Friedrich, G..... 1402
Fu, Hao-Jen..... 1370
Fuh, J.S..... 1503
Gardner, T.G..... 1445
Geiling, U..... 1371
Genta, G..... 1362
Geyer, K..... 1358
Ghosh, M..... 1496
Ghosh, S.K..... 1437
Gibbs, B.M..... 1405
Golla, D.F..... 1476
Goshorn, L..... 1423
Gottlieb, H.P.W..... 1424
Gould, P.L..... 1472
Green, I..... 1408
Griffin, J.H..... 1361
Grinfogel, L..... 1411
Grinnell, S.E..... 1462
Grootenhuis, P..... 1432
Gupta, A.K..... 1420
Gupta, B.K..... 1396
Gupta, U.S..... 1436
HaQuang, N..... 1471
Hashimoto, H..... 1443
Heppler, G.R..... 1439
Hughes, P.C..... 1476
Iannuzzelli, R.J..... 1360
Ioannides, E..... 1432
Irie, T..... 1442
Issa, C.A..... 1372
Iyengar, N.G.R..... 1431
Jamaleddine, A..... 1479
Jeon, G.J..... 1394
Jeong, G.D..... 1461

Jiang, Jiann-Kuo..... 1453
Juang, J.N..... 1418
Kaatzsch, U..... 1371
Kapania, R.K..... 1438
Kausel, E..... 1385
Kesavan, S.K..... 1458
Khulief, Y.A..... 1457
Kiryu, K..... 1407
Klauer, A..... 1486
Kobayashi, K..... 1450
Koga, T..... 1407
Kristensson, G..... 1435
Lai, Shyh-Shiun..... 1390
Lal, R..... 1436
Laura, P.A.A..... 1427, 1433
Laura, P.A.A..... 1498
Lawton, R.A..... 1484
Liebler, M.E..... 1377
Long, D.F..... 1456
Lundgren, T.S..... 1365
Malahy, R.C..... 1392
Mallik, A.K..... 1421
Manolis, G.D..... 1377
Matsumoto, S..... 1407
McFadden, P.D..... 1494
Mead, D.J..... 1419
Medury, Y..... 1393
Mehta, N.P..... 1396
Mei, Chuh..... 1415
Moehle, J.P..... 1379
Mook, D.T..... 1471
Moore, T.N..... 1369
Mourelatos, Z.P..... 1400
Mukherjee, A..... 1501
Muki, R..... 1441
Muramoto, Y..... 1442
Namba, M..... 1450
Nandlall, D..... 1466
Natke, H.G..... 1490
Nava, L.C..... 1427
Nicholson, J.W..... 1416, 1425, 1468
Nikolaidis, E..... 1363
Noguchi, T..... 1374
Nurhadi, I..... 1401
Oswald, B..... 1358
O'Hara, G.J..... 1465
O'Leary, P.M..... 1447
Pak, R.Y.S..... 1384
Pandit, M..... 1486
Papastavridis, J.G..... 1470
Parker, R..... 1488
Perz, P..... 1483
Piotrowski, J..... 1364
Plunkett, R..... 1412
Poltorak, K..... 1426
Prashad, H..... 1496
Prater, Jr., G..... 1475
Prucz, J.C..... 1404
Putcha, N.S..... 1428
Qian, Z.W..... 1452
Rastogi, P.K..... 1497
Reddy, E.S..... 1421, 1446
Reddy, J.N..... 1428
Reid, R.E..... 1495
Riaz, B..... 1459
Richards, E.J..... 1455, 1474
Roberts, J.W..... 1414
Roblee, J.W..... 1397
Roy, A.K..... 1412
Sabol, T.A..... 1375
Samanta, B..... 1501
Sanchez Sarmiento, G..... 1433
Sankar, B.V..... 1413
Sankar, S..... 1478
Schulz, R..... 1402
Sen, R..... 1385
Shabana, A.A..... 1457
Shah, A.H..... 1447
Shen, C.N..... 1499
Simulescu, I..... 1502
Singh, A..... 1396
Singh, R..... 1475
Sinha, A..... 1361
Skidmore, G.R..... 1477
Smith, E.L..... 1491
Smith, J.D..... 1494
Soares, F.R..... 1359
Soedel, W..... 1410
Solecki, R..... 1444
Starrh, L.I..... 1462
Stephens, J.E..... 1383
Stevens, K.K..... 1505
Stokes, A.N..... 1451
Stoneman, S.A.T..... 1488
Sudo, S..... 1443
Sun, C.T..... 1413, 1418
Sun, H.B..... 1474
Sun, J.C..... 1474
Surace, G..... 1434
Szemplinska-Stupnicka, W..... 1467
Tallin, A..... 1378
Tan, S.A..... 1386
Tani, J..... 1443
Tichy, J.A..... 1398
Triantafyllou, M.S..... 1411
Truman, K.Z..... 1373
Ulriksson, B..... 1485
Umaretiya, J.R..... 1431
Ventura Z., C.E..... 1480
Verma, C.P..... 1436
Walkington, N.J..... 1463
Wang, D..... 1399
Welsh, M.C..... 1451
Wight, J.K..... 1376
Williams, F.W..... 1417
Wuzhou, H..... 1422
Yamada, G..... 1442
Yanai, T..... 1407
Yazdani-Ardakani, S..... 1458
Yoerkie, C..... 1368

Yuen, M.M.F..... 1492
Zadoks, R.I..... 1410
Zaschel, J..... 1487

CALENDAR

JULY

14-16 Intersociety Environments Systems [SAE], San Diego, CA (412-776-4841)

20-24 Pressure Vessels and Piping Conference and Exhibition [ASME, concurrent with International Computers in Engineering Conference and Exhibit], Chicago, IL (212-705-7057)

20-24 International Computers in Engineering Conference and Exhibition [ASME] Chicago, IL (ASME)

21-23 INTER-NOISE 86 [Institute of Noise Control Engineering] Cambridge, MA (Professor Richard H. Lyon, Chairman, INTER-NOISE 86, INTER-NOISE 86 Secretariat, MIT Special Events Office, Room 7-111, Cambridge, MA 02139)

24-31 12th International Congress on Acoustics, Toronto, Canada (12th ICA Secretariat, P.O. Box 123, Station Q, Toronto, Ontario, Canada M4T 2L7)

SEPTEMBER

9-11 Rotating Machinery Dynamics, Bearings and Seals Symosium [Electric Power Research Institute, Coal Combustion Division] St. Louis, Missouri (Technical Information: Stanley Pace, Project Manager, CCS Division, Electric Power Research Institute, 3412 Hillview Ave., Palo Alto, CA 94304 415-855-2826; Registration information: Sharon Luongo, Conference Coordinator, Conferences & Travel Department, Electric Power Research Institute, 3412 Hillview Ave., Palo, Alto, CA 94304 415-855-2010)

14-17 International Conference on Rotordynamics [IFToMM and Japan Society of Mechanical Engineers] Tokyo, Japan (Japan Society of Mechanical Engineers, Sanshin Hokusei Bldg., 4-9, Yoyogi 2-chome, Shibuyak-ku, Tokyo, Japan)

16-18 Fall National Design Engineering Conference and Show (Cahners Exposition Group, New York, NY 203-964-0000)

21-23 Petroleum Workshop and Conference, Calgary, Canada (214-358-7601)

22-25 World Congress on Computational Mechanics [International Association of Computational Mechanics] Austin, Texas (WCCM/TICOM, The University of Texas at Austin, Austin, TX 78712)

29-30 VDI Vibrations Meeting [Society of German Engineers] Wurzburg, Fed. Rep. Germany (Society of German Engineers)

30-3 6th International Conference on Nondestructive Testing, Strasbourg, France (M.P. Pomes, 25 rue de Chong, 26500 Bourg les Valence, France)

OCTOBER

5-8 Design Automation Conference [ASME] Columbus, OH (ASME)

5-8 Mechanisms Conference [ASME] Columbus, OH (ASME)

7-9 2nd International Symposium on Shipboard Acoustics ISSA '86 [Institute of Applied Physics TNO] The Hague, The Netherlands (J. Buiten, Institute of Applied Physics TNO, P.O. Box 155, 2600 AD Delft, The Netherlands, Telephone: xx31 15787053, Telex: 38091 tpddt nl)

14-16 57th Shock and Vibration Symposium [Shock and Vibration Information Center] New Orleans, LA (Dr. J. Gordan Showalter, Acting Director, SVIC, Naval Research Lab., Code 5804, Washington, D.C. 20375-5000 - (202) 767-2220)

19-23 Power Generation Conference [ASME] Portland, OR (ASME)

20-22 Lubrication Conference [ASME] Pittsburgh, PA (ASME)

NOVEMBER

3-6 14th Space Simulation Conference [IES, AIAA, ASTM, NASA] Baltimore, MD (Institute of Environmental Sciences, 940 E. Northwest Highway, Mt. Prospect, IL 60056 - (312) 255-1561)

7-14 Turbomachinery Symposium, Corpus Christi, TX (Turbomachinery Laboratories, Dept. of Mech. Engrg., Texas A & M Univ., College Station, TX 77843)

30-5 American Society of Mechanical Engineers, Winter Annual Meeting [ASME] San Francisco, CA (ASME)

DECEMBER

7-12 ASME Winter Annual Meeting, Anaheim, CA (ASME, United Engrg. Center, 345 East 45th Street, New York, NY 10017)

8-12 ASA, Anaheim, CA (Joie P. Jones, Dept. Radiology Sciences, Univ. of California, Irvine, CA 92717)

CALENDAR ACRONYM DEFINITIONS AND ADDRESSES OF SOCIETY HEADQUARTERS

AHS American Helicopter Society
1325 18 St. N.W.
Washington, D.C. 20036

AIAA American Institute of Aeronautics and Astronautics
1633 Broadway
New York, NY 10019

ASA Acoustical Society of America
335 E. 45th St.
New York, NY 10017

ASCE American Society of Civil Engineers
United Engineering Center
345 E. 47th St.
New York, NY 10017

ASLE American Society of Lubrication Engineers
838 Busse Highway
Park Ridge, IL 60068

ASME American Society of Mechanical Engineers
United Engineering Center
345 E. 47th St.
New York, NY 10017

ASTM American Society for Testing and Materials
1916 Race St.
Philadelphia, PA 19103

ICF International Congress on Fracture
Tohoku University
Sendai, Japan

IEEE Institute of Electrical and Electronics Engineers
United Engineering Center
345 E. 47th St.
New York, NY 10017

IES Institute of Environmental Sciences
940 E. Northwest Highway
Mt. Prospect, IL 60056

IMechE Institution of Mechanical Engineers
1 Birdcage Walk, Westminster
London SW1, UK

IFToMM International Federation for Theory of Machines and Mechanisms
U.S. Council for TMM
c/o Univ. Mass., Dept. ME
Amherst, MA 01002

INCE Institute of Noise Control Engineering
P.O. Box 3206, Arlington Branch
Poughkeepsie, NY 12603

ISA Instrument Society of America
67 Alexander Dr.
Research Triangle Pk., NC 27709

SAE Society of Automotive Engineers
400 Commonwealth Dr.
Warrendale, PA 15096

SEE Society of Environmental Engineers
Owles Hall, Buntingford, Hertz.
SG9 9PL, England

SESA Society for Experimental Mechanics (formerly Society for Experimental Stress Analysis)
14 Fairfield Dr.
Brookfield Center, CT 06805

SNAME Society of Naval Architects and Marine Engineers
74 Trinity Pl.
New York, NY 10006

SPE Society of Petroleum Engineers
6200 N. Central Expressway
Dallas, TX 75206

SVIC Shock and Vibration Information Center
Naval Research Laboratory
Code 5804
Washington, D.C. 20375-5000

* U.S. GOVERNMENT PRINTING OFFICE:1986-491-626 / 40005

PUBLICATION POLICY

Unsolicited articles are accepted for publication in the **Shock and Vibration Digest.** Feature articles should be tutorials and/or reviews of areas of interest to shock and vibration engineers. Literature review articles should provide a subjective critique/summary of papers, patents, proceedings, and reports of a pertinent topic in the shock and vibration field. A literature review should stress important recent technology. Only pertinent literature should be cited. Illustrations are encouraged. Detailed mathematical derivations are discouraged; rather, simple formulas representing results should be used. When complex formulas cannot be avoided, a functional form should be used so that readers will understand the interaction between parameters and variables.

Manuscripts must be typed (double-spaced) and figures attached. It is strongly recommended that line figures be rendered in ink or heavy pencil and neatly labeled. Photographs must be unscreened glossy black and white prints. The format for references shown in **Digest** articles is to be followed.

Manuscripts must begin with a brief abstract, or summary. Only material referred to in the text should be included in the list of References at the end of the article. References should be cited in text by consecutive numbers in brackets, as in the following example:

> *Unfortunately, such information is often unreliable, particularly statistical data pertinent to a reliability assessment, as has been previously noted [1].*
>
> *Critical and certain related excitations were first applied to the problem of assessing system reliability almost a decade ago [2]. Since then, the variations that have been developed and practical applications that have been explored [3-7] indicate . . .*

The format and style for the list of References at the end of the article are as follows:

- each citation number as it appears in text (not in alphabetical order)
- last name of author/editor followed by initials or first name
- titles of articles within quotations, titles of books underlined
- abbreviated title of journal in which article was published (see Periodicals Scanned list in January, June, and December issues)
- volume, issue number, and pages for journals; publisher for books
- year of publication in parentheses

A sample reference list is given below.

1. Platzer, M.F., "Transonic Blade Flutter -- A Survey," Shock Vib. Dig., 7 (7), pp 97-106 (July 1975).

2. Bisplinghoff, R.L., Ashley, H., and Halfman, R.L., Aeroelasticity, Addison-Wesley (1955).

3. Jones, W.P., (Ed.), "Manual on Aeroelasticity," Part II, Aerodynamic Aspects, Advisory Group Aeronaut. Res. Dev. (1962).

Articles for the **Digest** will be reviewed for technical content and edited for style and format. Before an article is submitted, the topic area should be cleared with the editors of the **Digest.** Literature review topics are assigned on a first come basis. Topics should be narrow and well-defined. Articles should be 3000 to 4000 words in length. For additional information on topics and editorial policies, please contact:

Milda Z. Tamulionis
Research Editor
Vibration Institute
101 W. 55th Street, Suite 206
Clarendon Hills, Illinois 60514

DEPARTMENT OF THE NAVY

NAVAL RESEARCH LABORATORY, CODE 5804
SHOCK AND VIBRATION INFORMATION CENTER
Washington, DC 20375-5000

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

FIRST CLASS MAIL
POSTAGE & FEES PAID
USN
PERMIT No G 9

DEFENSE DOCUMENTATION CENTER

THE SHOCK AND VIBRATION DIGEST

Volume 18, No. 7 **July 1986**

EDITORIAL

1 SVIC Notes
2 Editors Rattle Space

ARTICLES AND REVIEWS

3 Feature Article — Substructuring and Component Mode Synthesis
R. Greif

9 Literature Review

11 Wave Propagation in Random Composite Materials
A.I. Beltzer

16 Book Reviews; and

CURRENT NEWS

19 Previews of Meetings
24 Short Courses

ABSTRACTS FROM THE CURRENT LITERATURE

26 Abstract Contents
27 Availability of Publications Abstracted
28 Abstracts: 86-1358 to 86-1505
64 Author Index

CALENDAR